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Mechanical Characteristics of Linear Asynchronous Motor

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Introduction

Usually, transportation of laminated products is done through rolls, put in rotation by electric motors. The acting moving force depends solely on the adherence of the laminated product to the moving rolls, which reduces the speed of the latter. The drawback of this speed limitation is most noticeable on the portions of the steel mill where, according to the work conditions, each metal sheet is to be rapidly stopped or pushed away (cutting zone, etc…). Since a large acceleration is not possible due to the resulting high inertial forces, a sliding of the bars on the rolls will occur. A solution to this problem may be obtained by using a linear asynchronous motor whose moving body would be the laminated product.

Developments: computation of the active forces in a LAM

In general, the energy transformation process in a LAM is analogous to that in usual asynchronous machines. In particular, in the absence of longitudinal border effects, (fig.1), we have the following ratios:

$$F_x = \frac{P_{EM}}{v_1} \tag{1}$$

and

$$F_x = \frac{p_2}{s v_1}, \tag{2}$$

where F_x – moving force; P_{EM} – active electromagnetic power transmitted to the moving body; p_2 – moving body electric losses; s – sliding; $v_1 = 2\tau f_1$ – field velocity with respect to the inductor; τ – pole step; f_1 – frequency.

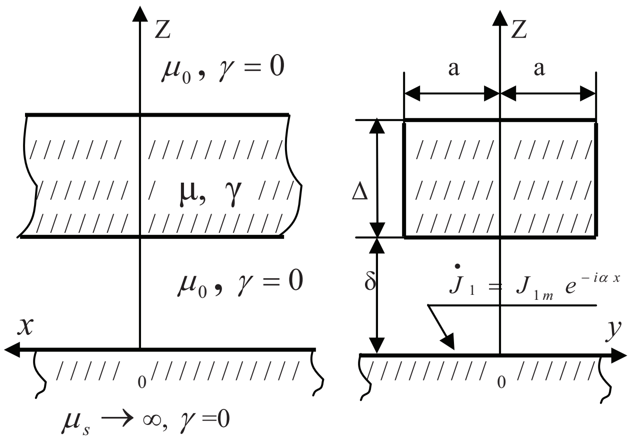

Fig. 1. LAM's computation model ($2a$ – moving body width; Δ – moving body thickness; δ – air gap; γ – electric conductivity; μ – magnetic permeability; μ_0 – air permeability).

Electromechanical power and power losses computations

For each elementary surface of the inductor, we have

$$dP_{EM} = -\mathrm{Re}\left(\frac{1}{2}\dot{E}\Big|_{z=0} \overset{*}{J}_1\right) dxdy, \tag{3}$$

where Re – indicates the real part; $\overset{*}{J}_1$ – complex conjugate of the inductor's linear current density; $\dot{E}\Big|_{z=0} = \dot{E}_m e^{-i\alpha x}$ – complex value of the electric field intensity on the inductor surface having a single component [1, 2], along the y – axis

$$\dot{E}_m\Big|_{z=0} = v_1 \dot{B}_{mz}\Big|_{z=0}, \tag{4}$$

where $\dot{E}_m$ – peak value of electric field intensity; B_{mz} – peak value of inductor.

In addition, since

$$\dot{B}_{mz}\Big|_{z=0} = \mu_0 \dot{H}_{mz}\Big|_{z=0} = -\mu_0 \frac{\partial \dot{U}_m}{\partial z}\Bigg|_{z=0} , \qquad (5)$$

where $\dot{H}_{mz}$ – complex amplitude of the magnetic field intensity; $\dot{U}_m$ – complex amplitude of the scalar magnetic potential.

Then

$$dP_{EM} = -\operatorname{Re}(\mu_0 \tau f_1 J_{1m} \frac{\partial \dot{U}_m}{\partial z}\Bigg|_{z=0})dydx , \qquad (6)$$

where $J_{1m} = \sqrt{2}Ak_b$ – the current density magnitude; A – linear load; k_b – winding factor.

Integrating with respect to y, we obtain the electromechanical power per unit inductor's length

$$\frac{P_{EM}}{L} = -2\mu_0 \tau f_1 J_{1m} \operatorname{Re}(\int_0^{L_1} \frac{\partial \dot{U}_m}{\partial z}\Bigg|_{z=0} dy) . \qquad (7)$$

It is necessary to set the outer limits at a far enough distance of the moving body [1.2]. In this case the scalar potential of the field with y=L1 and $z = L_2$ (fig.1) must represent the inductor's field potential in the absence of the moving body:

$$\dot{U}_m\Big|_{y=L_1} = -\frac{i}{\alpha} J_{1m} e^{-\alpha z} , \qquad (8)$$

$$\dot{U}_m\Big|_{z=L_2} = -\frac{i}{\alpha} J_{1m} e^{-\alpha L_2} . \qquad (9)$$

It has been shown [3] that the amount of electric losses in the conducting body can be computed as

$$p_2 = -\frac{1}{2} i\omega \oint (\overset{*}{H}_0 \dot{B}) dv , \qquad (10)$$

where $\overset{*}{H}_0$ – complex conjugate of the current intensity vectorial function; v – moving body volume.

Taking into account the periodic dependence of the field vector on the x–coordinate, we obtain the losses per unit active zone length as

$$\frac{p_2}{L} = -i\omega\mu_0 \int_\delta^\Delta \int_0^a [\overset{*}{H}_{0mz}(\dot{H}_{0mz} - \frac{\partial \dot{U}_m}{\partial z}) + \overset{*}{H}_{0my}(\dot{H}_{0my} - \frac{\partial \dot{U}_m}{\partial y})] dxdy . \qquad (11)$$

Computation of the acting forces in a LAM using a magnetic field tensor

The EM force vector acting on a moving body located in a magnetic field is

$$\overline{F} = \frac{1}{2}\mu_0 \operatorname{Re}\oint [\overset{*}{H}_m (\dot{H}_m \overline{n}) - \frac{1}{2}(\dot{H}_m)^2 \overline{n}] ds , \qquad (12)$$

where $\overset{*}{H}_m$ – complex conjugate of the field intensity; $\overline{n}$ – unit vector along the normal to the integrating surface; S – integrating surface surrounding the moving body and adhering to the surface on its outer side.

Using field symmetry with respect to the z–axis we obtain the components of the EM acting on the moving body per unit inductor length as:

$$\frac{F_X}{L} = \mu_0 \operatorname{Re}[\int_0^a (\overset{*}{H}_{mx} \dot{H}_{mz}\Big|_{z=\delta+\Delta} - \overset{*}{H}_{mx} \dot{H}_{mz}\Bigg|_{z=\delta}) dy + \int_\delta^\Delta (\overset{*}{H}_{mx} \dot{H}_{my}\Big|_{y=a}) dz] , \qquad (13)$$

$$\frac{F_x}{L} = \mu_0 \operatorname{Re}\{(\frac{1}{2}\int_0^a [(|\dot{H}_{mz}|^2 - |\dot{H}_{my}|^2 - |\dot{H}_{mx}|^2)|_{z=\delta+\Delta} - (|\dot{H}_{mz}|^2 - |\dot{H}_{my}|^2 - |\dot{H}_{mx}|^2)|_{z=\delta}] dy + \int_\delta^\Delta (\overset{*}{H}_{mz} \dot{H}_{my}\Big|_{z=\delta}) dz\} . \qquad (14)$$

The acting force on the moving body is equal in magnitude and opposite in direction to the force acting on the inductor; that's why F_x and F_z can also be determined from the field intensity values at the inductor surface:

$$\frac{F_x}{L} = -\mu_0 \operatorname{Re}(\int_0^{L_1} \dot{H}_{mx} \overset{*}{H}_{mz}\Big|_{z=0}) dy , \qquad (15)$$

$$\frac{F_z}{L} = -\frac{1}{2}\mu_0 \operatorname{Re}[(\int_0^{L_1} \dot{H}_{mz}\Big|_{z=0}^2 - J_{1m}^2) dy] . \qquad (16)$$

Since $\dot{H}_{mx}\Big|_{z=0} = J_{1m}$ and $\dot{H}_{mz}\Big|_{z=0} = -\frac{\partial \dot{U}_m}{\partial z}\Bigg|_{z=0}$,

then equations (14) and (16) along with (17) give the same result under all conditions. Equations (13), (15), (2) along with (10) are mutually independent and give the same result for F_x in a unique case where the field equations are satisfied, i.e., when is correctly computed with sufficient accuracy. This is also the case for equations (16) and (14) concerning F_z. Hence, computing the forces independently with different formula is a way of controlling the iterations in field computations and assessing the accuracy of the obtained results. All methods discussed above led to errors not exceeding 5 to 7% in the computation of the forces.

Mechanical characteristics computations: results and analysis

Fig. 2 and Fig. 3 represent the results of the computation of the LAM's characteristics.

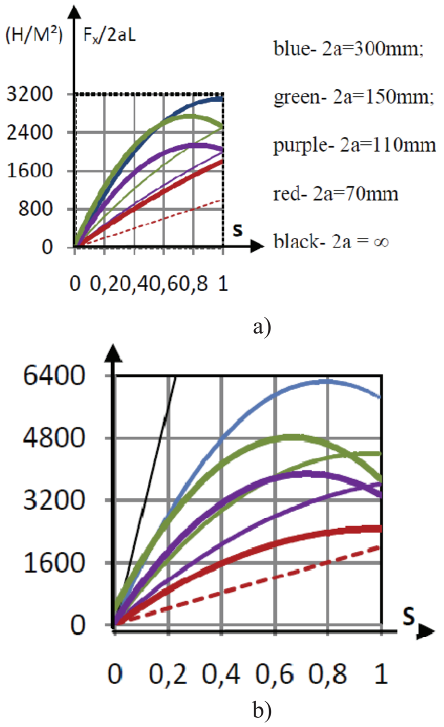

Fig. 2. Relationship between the specific motive force developed by the motor and the sliding: f=50 Hz (————); f=25 Hz (————): a – amagnetic moving body; γ = 1.4 10^{-7} 1/Ohm.m; b – magnetic moving body; γ = 7.52 10^{-6} 1/Ohm.m

In these figures are outlined the relationship between the specific forces, i.e., the forces per unit active zone surface and the sliding for different widths of the moving body.

Comparing these results with those of the infinite body's length allows the evaluation of the influence of the transversal border effect on the characteristics.

If this transversal border effect did not exist, specific forces would not be dependent on a and the corresponding curves, for different values of a, would coincide.

In fact, this dependence is important and the decrease in moving body's width will reduce considerably the specific forces.

Keeping the specific force constant while changing the width is not possible in light of frequency and voltage source regulation. Width increase reduces the influence of the transversal border effect on the characteristics.

The force in a ferromagnetic moving body is much greater than that of an amagnetic moving body. Globally, the analysis of the obtained results makes the use of a LAM in the transportation of metal sheets in a steel mill a real alternative due to the fact that it provides the required force.

In the case of unmagnetized sheets, the developed force by a unilateral motor may not be sufficient, especially for small moving bodies. The normal force in magnetised sheets is a repulsive force due to the electromagnetic interactions between primary and secondary currents. Not only the inductor attracts magnetized sheets but also the active force is much greater than the force developed by the motor. This can be explained by the strong electromagnetic interaction between the inductor and the metal sheets.

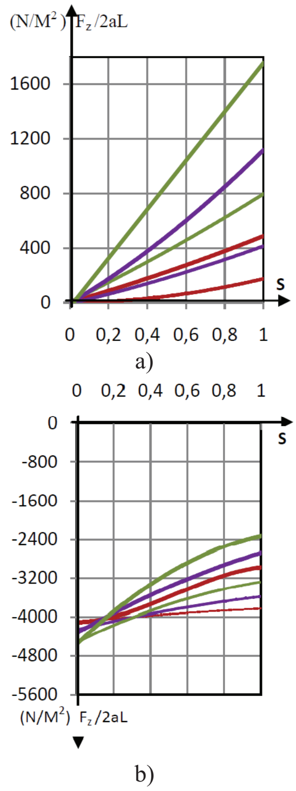

Fig. 3. Relationship between the specific normal force developed by the motor and the sliding: f=50 Hz (————); f=25 Hz (————): a – amagnetic moving body; γ = 1.4 10^{-7} 1/Ohm.m; b – magnetic moving body; γ = 7.52 10^{-6} 1/Ohm.m

As sliding increases, this force decreases due to the interaction between primary and secondary currents. This force will also be useful in cases where the conveyor has moving rolls since it will increase adherence of sheets to the rolls, improving this way efficiency.

Conclusions

In this work, magnetic field and acting forces computations were carried out in a LAM used for the transportation of magnetized and unmagnetized metal sheets in a steel mill.

Analysis of the results concluded to the possibility of using this type of motors since it provides the required force.

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This work is concerned with the computations of the active forces in a unilateral linear asynchronous motor (LAM) without an inverse magnetic circuit, for both magnetic and unmagnetic moving bodies. Field and force computations were conducted and results analyzed. Ill. 3, bibl. 4 (in English; abstracts in English and Lithuanian).

A. Boudiaf, Z. Aissani, A. Bentriou. Tiesiaeigio asinchroninio variklio mechaninių charakteristikų tyrimas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2011. – Nr. 4(110). – P. 21–24.

Analizuojamos aktyviosios jėgos, veikiančios tiesiaeigiame asinchroniniame variklyje. Tiriama magnetinės grandinės be grįžtamojo ryšio situacija. Atlikti ir patikrinti magnetinio lauko ir jėgų skaičiavimai. Il. 3, bibl. 4 (anglų kalba; santraukos anglų ir lietuvių k.).