LINEAR MOTOR FOR DRIVE OF BELT CONVEYOR

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Summary This paper introduces a novel approach on the design of a linear motor for drive of belt conveyor (LMBC). The motor is a simple combination of asynchronous motor in plane. The electromagnetic forces is one of the most important parameters of electrical machines. This parameter is necessary for the checking of the design. This paper describes several variants: linear motor with slots in platens, slots in one half of platens and optimization of slots. The electromagnetic force can be found with the help of a Finite Elements Method – based program. For solution was used QuickField program.

1. INTRODUCTION

So far we have examined the fundamental operating principles of electric machines that produce rotation or circular motion. During the last few decades, extensive research in the area of propulsion has led to the development of linear motors. Theoretically each type of rotating machine may find a linear counterpart. However, it is the linear induction motor that is being used in a broad spectrum of such industrial applications as high-speed ground transportation, sliding door systems, curtain pullers, and conveyors.

If an induction motor is cut and laid flat, a linear induction motor is obtained. The stator and rotor of the rotating motor correspond to the primary and secondary sides, respectively, of the linear induction motor. The primary side consists of a magnetic core with a three phase winding, and the secondary side may be just a metal sheet or a three-phase winding wound around a magnetic core.

The basic difference between a linear induction motor and its rotating counterpart is that the latter exhibits endless air-gap and magnetic structure, whereas the former is open-ended owing to the finite lengths of the primary and secondary sides. Also, the angular velocity becomes linear velocity, and the torque becomes the thrust (force) over a considerable distance, one side is kept shorter than the other.

For example, in high-speed ground transportation, a short primary part and a long secondary part are being used. In such a system, the primary is an integral part of the vehicle, whereas the track manifests as the secondary.

A linear induction motor may be single-sided or double-sided, as shown in Fig. 1.,2.,3. [1], [2], [6]. In order to reduce the total reluctance of the magnetic path in a single- sided linear motor with a metal sheet as the secondary winding, the metal sheet is backed by ferromagnetic material such as iron.

2. CONSTRUCTION

The construction of LMBC – Fig. 4 - is very simple and is like in its principle of operation the asynchronous machine. The moving element is called the forcer. The stationary part is called the platen.

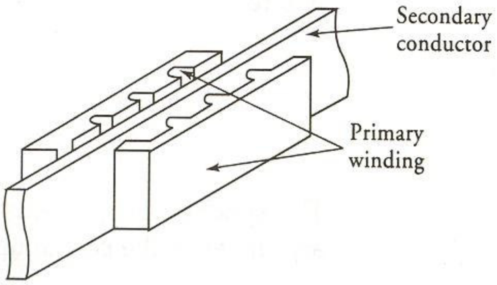

Fig. 1. Double-sided linear induction motor

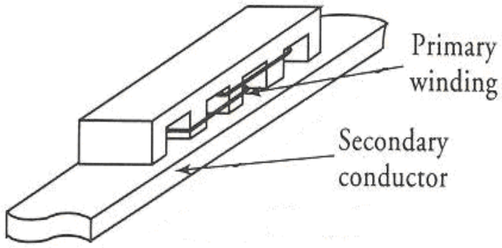

Fig. 2.Single-sided linear induction motor

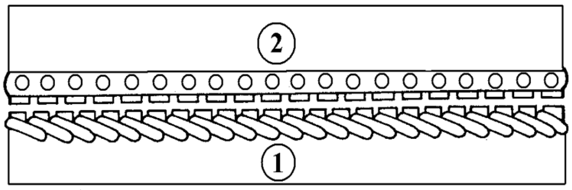

Fig 3. Cross section of induction motor in plane

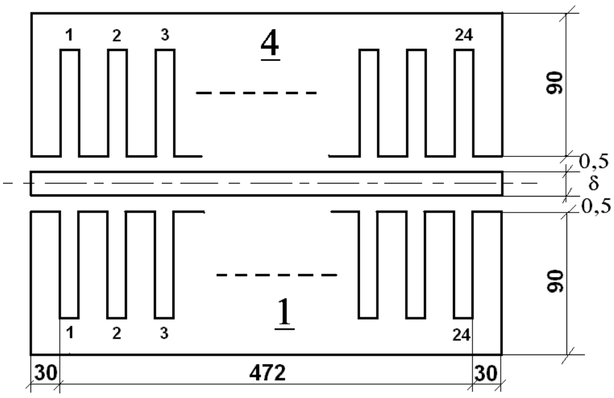

Fig. 4. Geometrical sizes of LMBC

For the opposite forcer are possible arrangements as in Table 2. Sizes of slots are given in Table 1. Fig. 5. shows the Tingley diagram of the winding. The placement of the U-phase shows Fig. 6.

Tab. 1. Parameters of slots

Var. 1	Var. 2
Slot ratio b:h, 12:60 mm, $S_W = 720 mm^2$ $J_W = 4\ A/mm^2$ $I_W = 2880$ A	Slot ratio b:h, 12:48 mm, $S_W = 576 mm^2$ $J_W = 5\ A/mm^2$

Var. 3	Var. 4
Slot ratio b:h, 12:36 mm, $S_W = 576 mm^2$ $J_W = 5\ A/mm^2$	Slot ratio b:h, 12:60 mm, $S_W = 720 mm^2$ $J_W = 4\ A/mm^2$ $I_W = 2880$ A

Parameters of windings:

Number of poles	4
Number of phases	3
Mathematical number of phases	6
Number of slots	24
Number of slots per pole per phase	2

Parameters of active parts:

$\gamma_{Cu} = 5{,}7.10^7$ [S.m^{-1}]
$\gamma_{Al} = 3{,}4.10^7$ [S.m^{-1}]
$\gamma_{Fe} = 5.10^6$ [S.m^{-1}]
$\mu_r = 500$ for elt. sheets

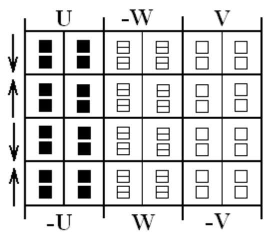

Fig. 5. Tingley diagram

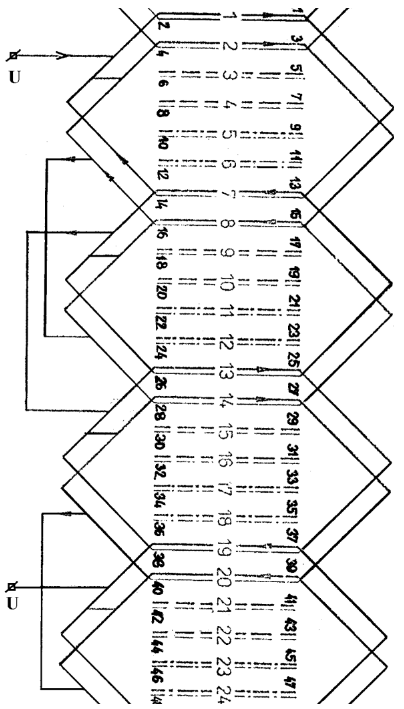

Fig. 6. Placement of phase winding

3. THEORETICAL MODEL

In the given case it is necessary to express time harmonically the electromagnetic field valuables for ferromagnetic environment then the eddy currents for electrically conductive and non-ferromagnetic part, and finally Lorenz forces caused by the existence of the field and eddy currents. The mentioned electromagnetic field in the nonlinear environment B(H) is described (for details see e.g. [4]) with the help of vector potential **A**(x, y, t) by partial differential equation [7].

$$rot\frac{1}{\mu}rot\boldsymbol{A}+\gamma\frac{\partial \boldsymbol{A}}{\partial t}=\boldsymbol{J}_b \qquad (1)$$

The equation can be replaced, in case of a simpler, linear problem and supposing that the field current I_b or vector of its current density $\overline{J_b}$ are harmonic variables with frequency f by Helmholtz equation

$$rotrot\underline{\boldsymbol{A}}+j\omega\gamma\mu\underline{\boldsymbol{A}}=\mu\underline{\boldsymbol{J}_b} \qquad (2)$$

for phasor $\underline{A}(x,y)$ of vector potential A(x, y, t).

The vector of consequent eddy currents $\boldsymbol{J}_{eddy}$, or its phasor $\overline{\boldsymbol{J}_{eddy}}$, cause in time changing electromagnetic field in electrically conductive environment (e.g. in a sliding element of linear motor) is given by the relation

$$\gamma \frac{\partial \boldsymbol{A}}{\partial t} = \boldsymbol{J}_{eddy} \qquad (3a)$$

$$j\gamma\omega \underline{\boldsymbol{A}} = \underline{\boldsymbol{J}}_{eddy} \qquad (3b)$$

The vector of Lorentz force $\boldsymbol{F}_{\mathrm{L}}$ which is operating on the sliding element of the linear motor and which has in given case mean value $\boldsymbol{F}_{\mathrm{Ls}}$ and oscillation component V$\boldsymbol{F}_L$ is then given by relation

$$\boldsymbol{F}_L = \int_V (\boldsymbol{J}_{eddy} \times \boldsymbol{B}) dV \qquad (4a)$$

or

$$= \int_V (\underline{\boldsymbol{J}}_{eddy} \times \underline{\boldsymbol{B}}) dV \qquad (4b)$$

where $\boldsymbol{B} = \mathrm{rot}\,\boldsymbol{A}$ and V is the volume of sliding/shifting element. At the same time the following is valid:

$$\boldsymbol{F}_L = \boldsymbol{x}_0 F_{L,x} + \boldsymbol{y}_0 F_{L,y} \qquad (5)$$

The solution of the given mathematical model was carried out by MKP programme Quick Field, version 5.0 [3].

The convergence of solution was monitored that guarantees the accuracy of calculations $\boldsymbol{F}_{\mathrm{L}}$ to three valid digits [9]. At the same time the boundary conditions describing the existence of considered linear motor in unlimited, non-ferromagnetic homogenous environment were respected.

4. RESULTS

The forces were calculated for different geometrical arrangements of LMBC. To calculate the force, the assumption that the currents and the voltages are sinusoidal is made. Results of calculation are given in Table 2. Solution to the equation (4a, 4b) by software Quick Field [3] over the mesh provided the distribution of $\boldsymbol{A}$(x,y) (Fig. 4,5,6,7,8) are presented.

Fig. 7. shows the LMBC where sheets are in $\underline{1}$ and $\underline{4}$ arrangements.

Fig.8. shows the detail of the LMBC, the map of the magnetic field with Al plate.

Fig.9. shows the LMBC with the aluminum plate (part 4 is the air).

Fig.10. – detail, Fe plate.

Fig. 11. shows the Fe plate, moving out from the air-gap.

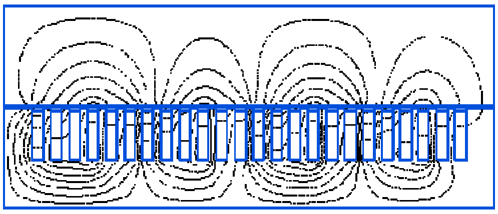

Fig. 7. Map of the magnetic field

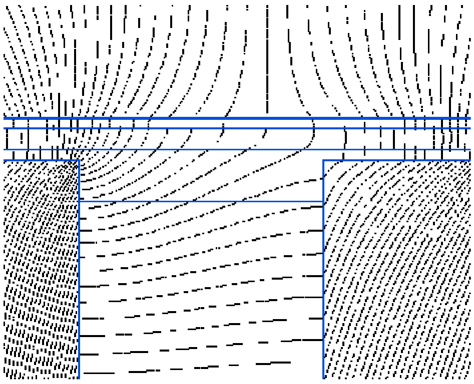

Fig. 8. Detail of the LMBC, Al plate

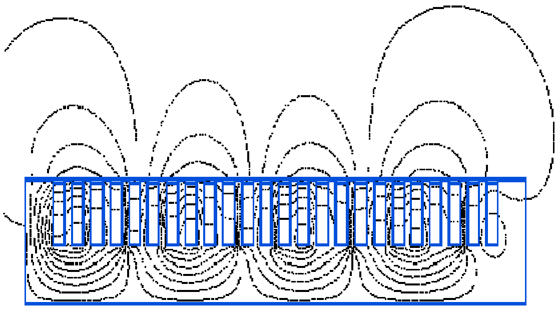

Fig. 9. Map of the magnetic field, $\underline{4}$ – air arrangements

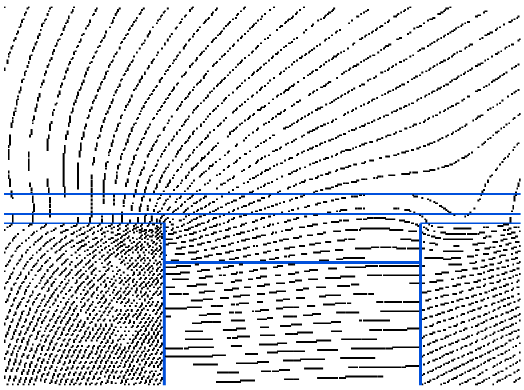

Fig. 10. Detail of the LMBC, Fe plate

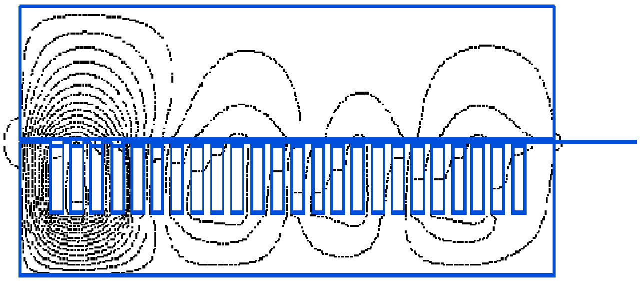

Fig.11. Magnetic short circuit, Fe plate

Tab. 2. Results of calculations

Slot	Arragements 4		Steel 1, 4	F_{LX} [N]	F_{LY} [N]	ΔF_L [N]
Var. 1	ALT 1B2 slots without wires		Sheets	594	168	7
			Massive	57	33	0,7
	ALT 1B3 steel without slots		Sheets	600	169	7
			Massive	99	37	0,6
	ALT 1B4 air		Sheets	117	37	12
			Massive	35	11	2
Var. 2	ALT 1C3 steel without slots		Sheets	609	171	7,1
			Massive	131	47	1
	ALT 1C4 air		Sheets	118	37	12,1
			Massive	46	14	2,7
Var. 3	ALT 1D3 steel without slots		Sheets	612	173	7,1
			Massive	169	60	1,1
	ALT 1D4 air		Sheets	119	38	12,1
			Massive	58	18	3,9
Var. 4	Steel without slots	δ_{Cu}=1mm	Sheets	363	180	5,2
		δ_{Al}=2mm		306	178	5,7
		δ_{Al}=4mm		150	180	4,8
		δ_{Fe}=1mm		2673	51988	5733
	with. Fe	δ_{Fe}=1mm		713	8057	4883,9

5. CONCLUSION

- It is proved that a massive block significantly increase the force on the aluminum forcer.
- The force is influenced the electric and magnetic properties of the forcer, sizes and orientation.
- The sizes of the slot have not the fundamental influence on values of the forces.
- The force is decreasing when the forcer begin to move out from the LMBC. The reason is the magnetic short-circuit.
- A massive block of the platen is not advantageous but is more frequented.

Nomenclature

B[T]	magnetic flux density
S[m^2]	surface
J[A.m^2]	electric current density
I[A]	current
A[Tm]	magnetic vector potential
μ[H.m^{-1}]	magnetic permeability
γ[S.m^{-1}]	electric conductivity
V[m^3]	volume
F[N]	force
δ[m]	geometrical size

Acknowledgement

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REFERENCES

[1] Guru, B. S. , Hiziroglu, H. R.: Electric machinery and transformers. *Oxford University Press.2001.*

[2] Daud, A.K., Hanitsch, R.: Design of hybrid linear stepping motor (HLSM) for long stroke operation.*ICEM2004.*

[3] *Manual QUICKField*

[4] Bianchi, N.: Electrical machines analysis using finite elements. CRC Press. 2005.

[5] Chapman, S.J.: Electric Machinery. New York McGraw-Hill, 1985.

[6] Laithwaite, E.R.: Linear Electric Motors, Mills & Boon Limited, London 1971.

[7] Haňka, L.: Teorie elektromagnetického pole. SNTL Praha 1973.

[8] Ralston, A.: A first course in numerical analysis. McGraw-Hill Book Co., NY. (in Czech: ACADEMIA Praha, 1973).

[9] Capova, K., Faktorova, D., Marek, T.: The eddy current method using in non-destructive testing. AMTEE, Pilsen, 2005. pp. C13-C18.