September 10 - 12, 2007
Pilsen, Czech Republic

ELECTRICAL MACHINES OPTIMISATION – LINEAR MOTOR

Ing. Milan Krasl, Ph.D.
Bc. & Ing. Rostislav Vlk, Ph.D.

Abstract: *This paper introduces a novel approach on the design of a linear synchronous motor for drive of belt conveyor (LSM). The motor is a simple combination of asynchronous motor in plane. This parameter is necessary for the checking of the design. This paper describes several variants: linear motor with slots in platens and various forcers. The electromagnetic force can be found with the help of a Finite Elements Method – based program. For solution was used FEMM program.*

Key words: *linear synchronous motor, FEM, Lorenz forces.*

INTRODUCTION

Linear electric motors [2] can drive a linear motion load without intermediate gears, screws or crank shafts. A linear synchronous motor is a linear motor in which the mechanical motion is the same as the speed of traveling magnetic field. The force can be generated as an action of

- traveling magnetic field produced by a polyphase winding and an array of magnetic poles N,S…..N, S or a variable reluctance ferromagnetic rail
- magnetic field produced by electronically switched d.c. windings and an array of magnetic poles N,S,…..N,S or variable reluctance ferromagnetic rail (linear stepping or switched reluctance motors)

In the case of LSMs operating on the principle of traveling magnetic field, the speed v of the moving part

$$v = v_S = 2.f.\tau = (\omega/\pi).\tau \tag{1}$$

is equal to the synchronous speed v_S of the travelling magnetic field and depends only on the input frequency f and pole pitch τ.. It does not depend on the number of poles $2p$.

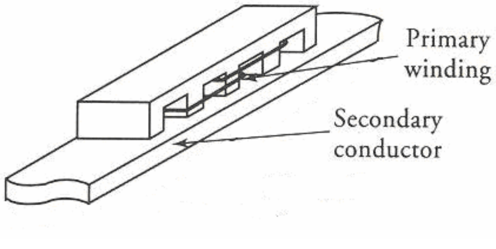

Fig.1: Single-sided linear induction motor

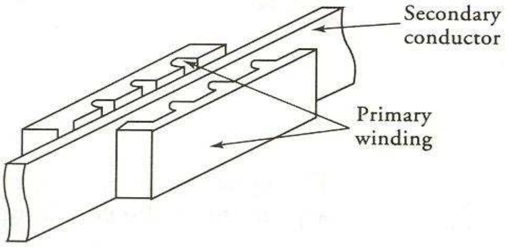

Fig. 2. Double-sided linear induction motor

1 CONSTRUCTION

The construction of LSM (Linear Synchronous Motor) – Fig. 3 - 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.

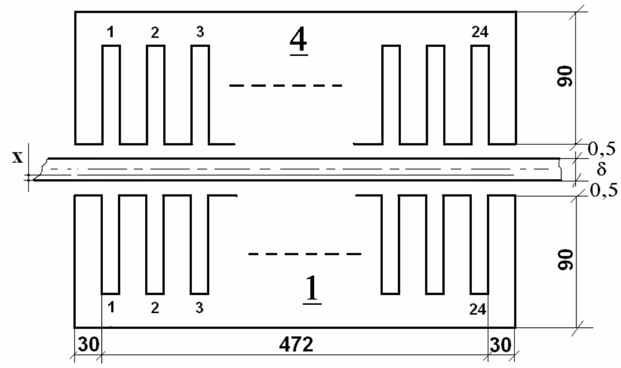

Fig. 3. Geometrical sizes of LSM

Parameters of motor:	
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

Slot ratio b:h,
12:60 mm,
S_W = 720mm2
J_W = 4 A/mm2
I_W = 2880 A

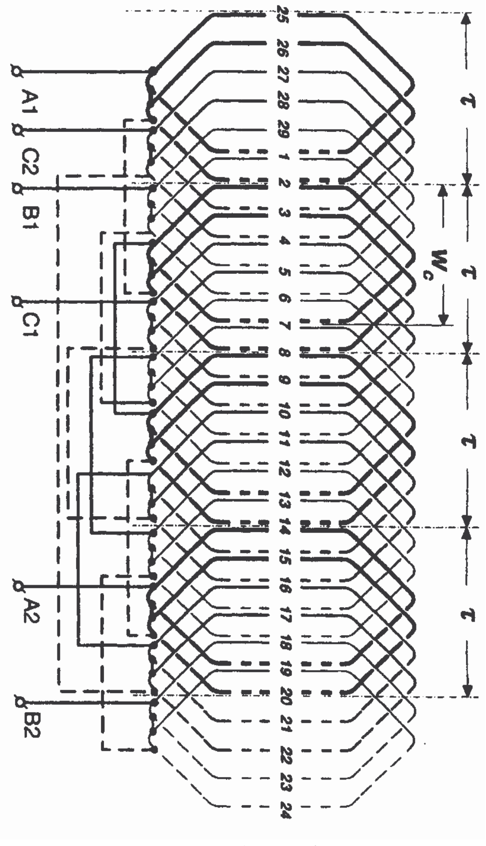

Fig. 4. Windings

2 THEORETHICAL 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. [1]) with the help of vector potential A(x, y, t) by partial differential equation [1].

$$rot\frac{1}{\mu}rot\boldsymbol{A} + \gamma\frac{\partial \boldsymbol{A}}{\partial t} = \boldsymbol{J}_b \qquad (2)$$

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 $\underline{\boldsymbol{J}}_b$ are harmonic variables with frequency f by Helmholtz equation.

$$rotrot\underline{\boldsymbol{A}} + j\omega\gamma\mu\underline{\boldsymbol{A}} = \mu\underline{\boldsymbol{J}_b} \qquad (3)$$

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

The vector of consequent eddy currents $\boldsymbol{J}$, 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

$$\gamma\frac{\partial \boldsymbol{A}}{\partial t} = \boldsymbol{J}_{eddy} \qquad (4a)$$

$$j\gamma\omega\underline{\boldsymbol{A}} = \underline{\boldsymbol{J}}_{eddy} \qquad (4b)$$

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

$$\boldsymbol{F}_L = \int_V \left(\boldsymbol{J}_{eddy} \times \boldsymbol{B}\right) dV \qquad (5a)$$

or

$$= \int_V \left(\underline{\boldsymbol{J}}_{eddy} \times \underline{\boldsymbol{B}}\right) dV \qquad (5b)$$

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

$$\boldsymbol{F}_L = \boldsymbol{x_0}F_{L,x} + \boldsymbol{y_0}F_{L,y} \qquad (6)$$

The solution of the given mathematical model was carried out by FEM programme FEMM, version 4.0.

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

3 RESULTS OF CALCULATIONS

The forces were calculated for different geometrical arrangements of LSM. To calculate the force, the assumption that the currents and the voltages are sinusoidal is made. Results of calculation are given in Table 1. Solution to the equation (5a, 5b) by software FEMM over the mesh provided the distribution of A(x,y) or B[T], (Fig. 5 - 12) are presented.

Fig. 5. shows the LSM with Cu plate.

Fig.6.,7. shows the detail of the LSM, the map of the magnetic field, plate 1mm Cu, 3mm Fe.

Fig. 8. shows the Cu+Fe plate, moving out from the air-gap.

The solution of the given mathematical model was carried out by FEM programme FEMM, version 4.0 – results in Tab.1

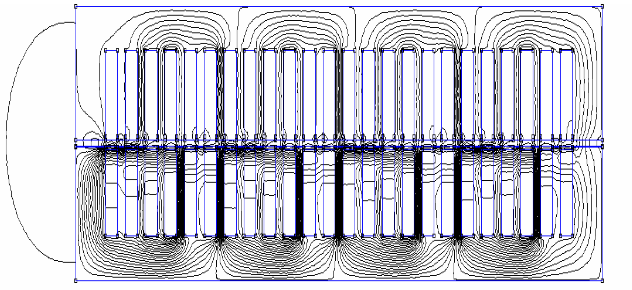

Fig. 5. Map of the magnetic field, Cu plate

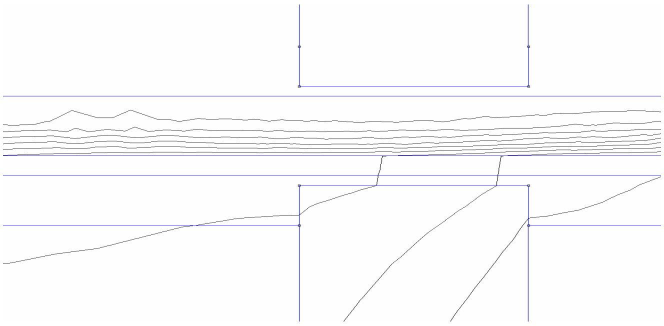

Fig. 6. Map of magnetic field

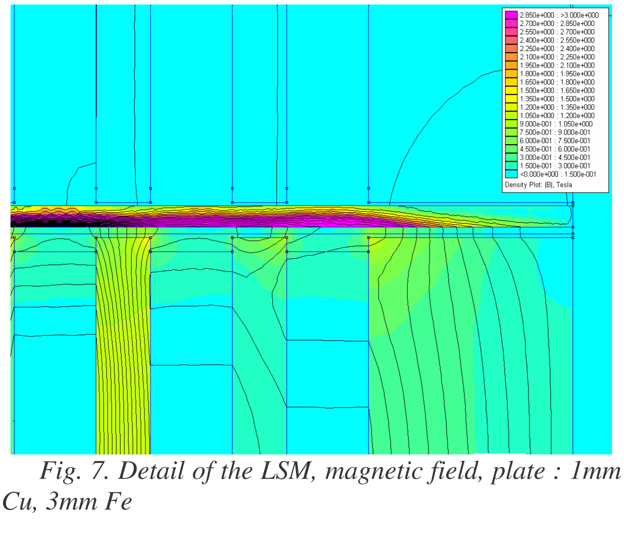

Fig. 7. Detail of the LSM, magnetic field, plate : 1mm Cu, 3mm Fe

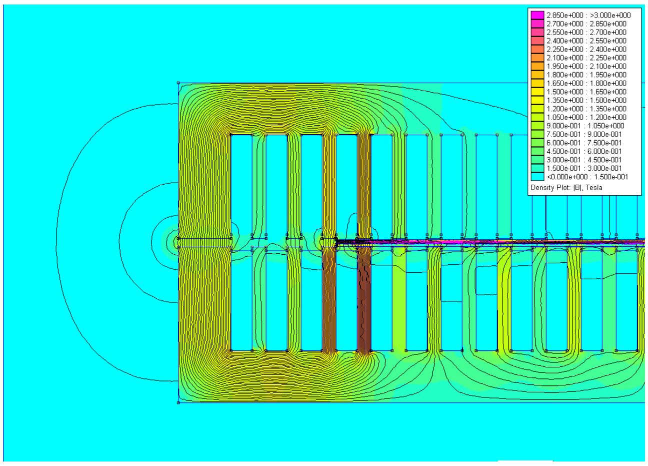

Fig. 8. Detail of the LSM, magnetic field, plate : Cu 1mm, Fe 3mm, moving out from the air-gap

Version	Distance x [mm]	Fx [N/1mm]	Fy [N/1mm]
with opposite part	0	-1.399	2.993
	1	-5.347	12.94
	2	-2.673	5.855
	3	-1.775	3.76
without opposite part	0	-1.35	2.607
	1	-5.356	12.02
	2	-2.696	4.42
	3	-1.79	3.15

Tab. 1: Results of calculations

4 CONCLUSION

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 LSM. The reason is the magnetic short-circuit.

5 REFERENCES

[1] M. Krasl, B. Ulrych : Linear motor for drive of belt conveyor. ELEKTRO 06. Zilina.2006. Slovakia
[2] J. F. Gieras, Z. J. Piech: Linear synchronous motor, CRC Press, 2000.

6 ACKNOWLEDGEMENT

This work has been supported by the project no. GA CR 102/05/0942.