COMPARATIVE STUDY ON LINEAR TRANSVERSE FLUX RELUCTANCE MACHINES

Vasile IANCU – Dan-Cristian POPA – SZABÓ Loránd – Mircea RUBA – Emil TRIFU
Electrical Machines Department
Technical University of Cluj-Napoca
400750 Cluj-Napoca, P.O. Box 358, Romania
e-mail: Vasile.Iancu@mae.utcluj.ro

Abstract ***– New structures of transverse flux linear machines (TFM) are presented in this paper. Starting from a new type of TFM the authors will make a comparison between the proposed variants of machines. Considering that the TFM is a relative newcomer in the field of the special electrical machines, it is important to approach this problem from different points of view in order to see the possible advantages of using this type of machine in different applications. After analyzing the performances of the above mentioned TFM some conclusions will be drawn.***

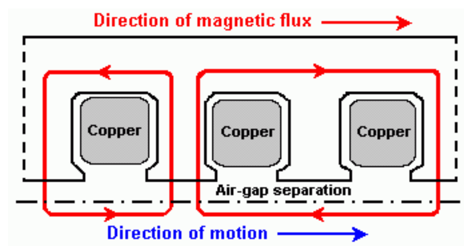
Keywords: ***transverse flux machines, linear machines, 3D FEM analysis***

I. INTRODUCTION

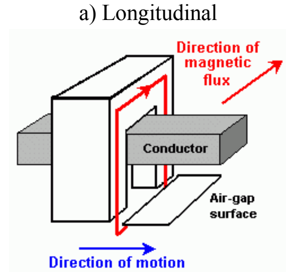
Until now several types of TFMs were presented, all of them deriving from three main variants: one with active rotor having permanent magnets in it, and two structures with passive rotor. After closely analyzing these variants and different linear machines (especially the hybrid linear stepper motors) the authors a new structure of transverse flux linear machine has proposed. It is in fact a variable reluctance machine of modular type. It is a combination between a TFM with passive rotor and a stator with permanent magnets on it and a hybrid linear stepper motor. Beside this structure also a variant without permanent magnets on the mover was analyzed.

II. A NOVEL LINEAR TFM

The electrical machines have various topologies. In general terms the iron core carries magnetic flux around the windings of the machine in order to create an electromotive force. The magnetic flux can pass in a direction parallel, or mainly perpendicular to the direction of motion (see Fig. 1). In the first case, the machine is said to be longitudinal, and in the second case transverse [1].



a) Longitudinal



b) Transversal

Fig. 1. Magnetic flux orientation in electrical machines.

The linear machine structure to be presented also has the magnetic flux path transversal to the direction of its movement. It was obtained by combining the modular structure of the double salient permanent magnet linear motor given in Fig. 2 with a linear variant of a transverse flux machine with permanent magnets (PMs) on the stator and passive rotor [2].

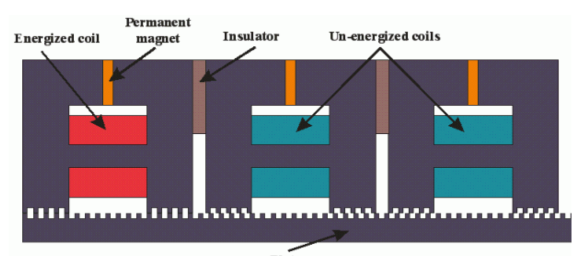


Fig. 2. The modular double salient PM linear motor.

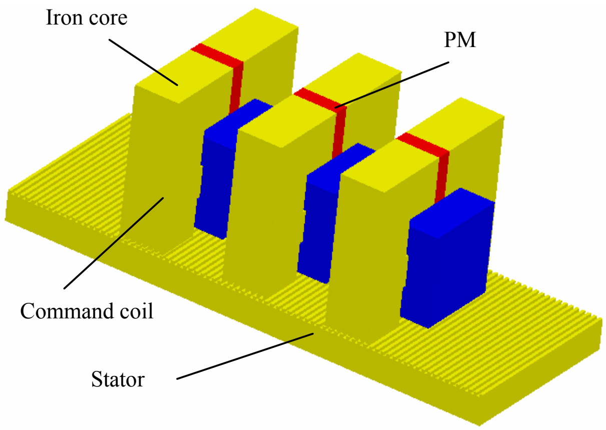


Fig. 3. The proposed modular linear machine.

The three-phase variant of the proposed linear motor is given in Fig. 3. A three-phase (three modules) variant was selected because of the easy implementation of the control strategy on general purpose three-phase power converters [3].

The iron core of the module is shown in Fig. 4. It is very similar to that of the modular double salient permanent magnet linear motor given in Fig. 2. The single basic difference is that the poles of this variant are toothed in the transverse direction [4].

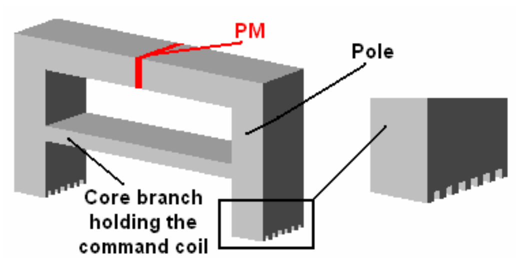


Fig. 4. The iron core of the mover.

The working principle of the machine can be understood upon Fig. 5 and it is identical with that of the modular double salient permanent magnet linear motor given in Fig. 2.

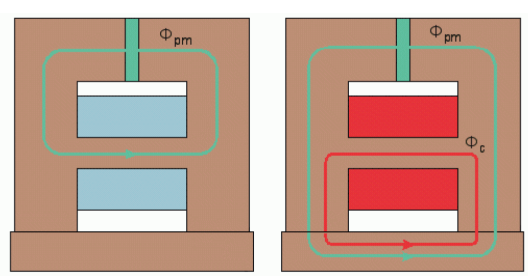


Fig. 5. The working principle of the linear machine.

When the module is passive the flux generated by the permanent magnet closes mostly inside the mover's iron core. When the command coil is energized, the magnetic flux produced by the winding practically enforces the flux of the permanent magnet through the air-gap, generating this way tangential and normal forces in a manner as in the case of the double salient permanent magnet linear motor shown in Fig. 2 [2].

The proposed linear machine structure is in fact a variable reluctance machine (linear transverse flux reluctance machine LTFRM). Its movement is possible only if the modules are shifted by a third of the teeth pitch. Energizing the command coil of one module its teeth will be aligned with the teeth of the platen. By sequential feeding of the command coils continuous linear movement of any direction can be assured [3].

The detailed design procedure of the proposed linear machine was presented in previous papers [3].

Here only the main dimensions of the sample motor's modules are given. In Fig. 6 both the lateral and frontal view of a module is given.

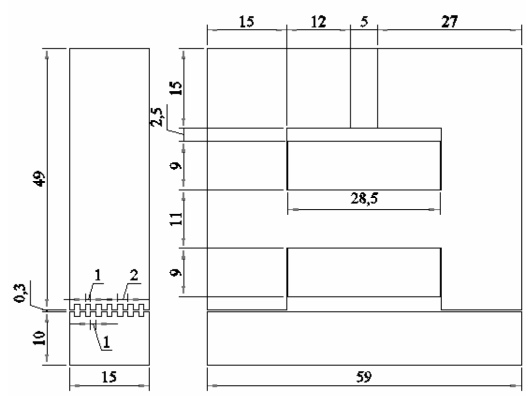


Fig. 6. Main sizes of proposed linear TFM module (lateral and frontal view)

III. 3D FEM ANALYSIS OF THE LINEAR TFM

The designed structure of the proposed modular linear machine was analyzed by means of three-dimensional (3D) finite elements method based numerical magnetic field computation.

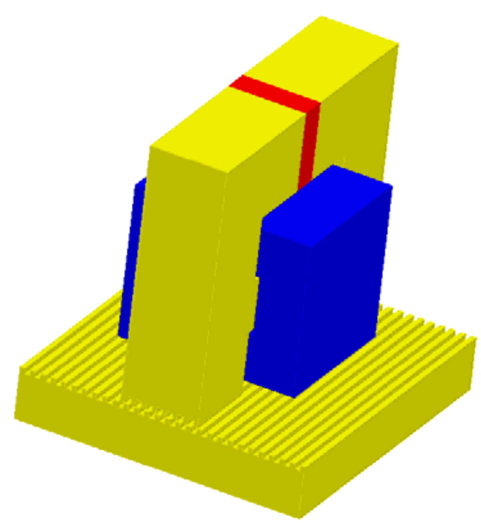
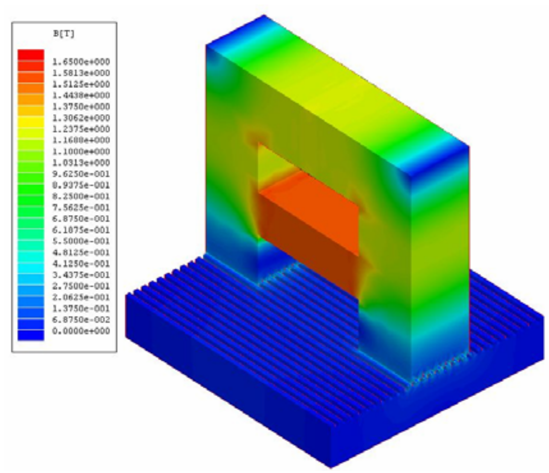


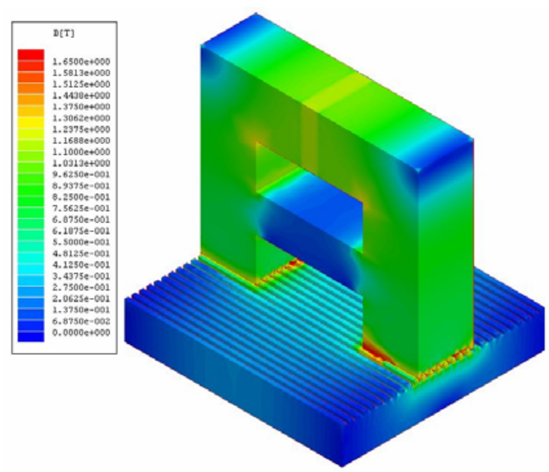
Fig. 7. The analyzed LTFRM structure with PMs on the mover.

As in any time moment only a single module is active in the linear machine it was enough to analyze only a single module and the portion of the stator under it (as shown in Fig. 7).

The results of the field analysis are given in Fig. 8. The distribution of the flux density in the machine both in the case of the passive and active module is given. The results completely prove the working principle of the modular linear motors.



a) passive module



b) active module

Fig. 7. The flux density distribution obtained via 3D FEM analysis for the LTFRM with PMs on the mover on the mover

The maximum force is not obtained when the teeth of one mover's module are shifted with a third of a teeth pitch. However, all the forces computed by FEM here are obtained just for this situation.

On the basis of the studies formerly carried out by the authors it could be stated out that the height of the core branch should have a small influence on the tangential and normal forces developed by the machine. This conclusion is supported by the results given in Table 1:

Table 1: Forces developed by the LTFRM with PMs on the mover

Height of the core branch	Tangential force	Normal force
5 mm	5.13 N	57.53 N
11 mm	5.15 N	55.91 N
15 mm	5.1 N	56.93 N

As a comparative situation it was considered the case of the machine without PMs on the mover. The obtained structure is presented in Fig. 8. As mentioned for the previous linear transverse flux reluctance machine (LTFRM with PMs), it is enough to analyze only a single module and the portion of the stator under it.

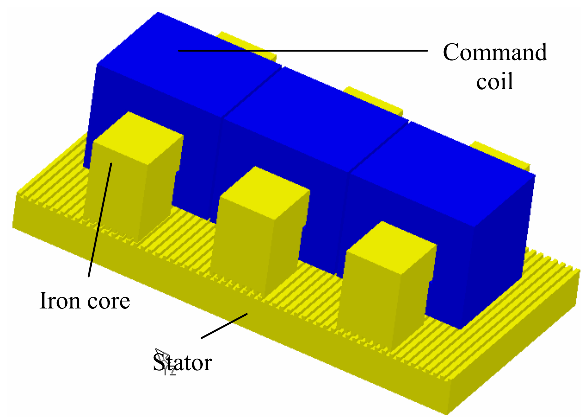


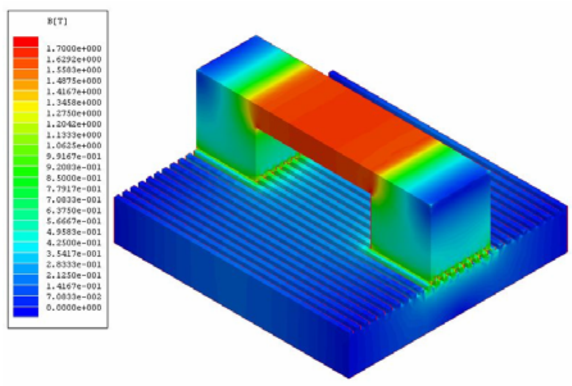
Fig. 8. LTFRM without PMs

In this case the height of the so called core branch has a very big significance over the tangential force developed as we will show next. There were analyzed three situations, the same cases like for the LTFRM with PMs on the mover. The only dimension which differs is the height of the so called before core branch, all the geometrical values were maintained the same as for the other structure. Also the magneto-motive force of the coil used for the LTFRM without PMs has the same value as before. The forces computed via 3D FEM are presented in Table 2:

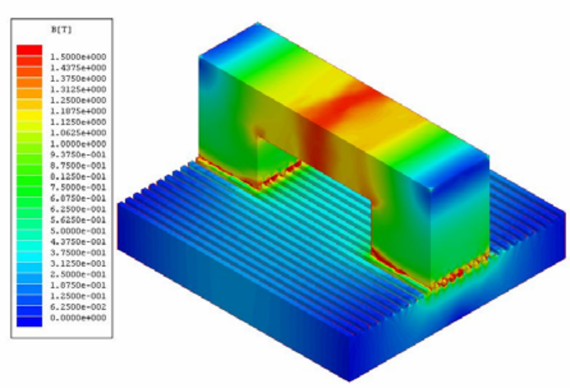
Table 2: Forces developed by the LTFRM without PMs on the mover

Height of the core branch	Tangential force	Normal force
5 mm	2.52 N	26.94 N
11 mm	4.8 N	51.53 N
15 mm	5.04 N	54.36 N

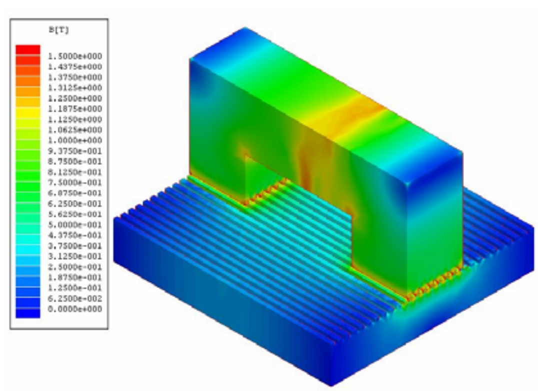
As it can be seen the forces are fairly equal for the LTFRM with PMs for different height of the core branch but differ consistently for the machine without PMs with the variation of the core branch's height. Also it can be noticed that for the case of the LTFRM without PMs having the iron core with the same section in all its parts the forces are very close to the ones obtained for the other variant of LTFRM.



a) LTFRM with core branch’s height of 5 mm



b) LTFRM with core branch’s height of 11 mm



c) LTFRM with core branch’s height of 15 mm

Fig. 9. The flux density distribution obtained via 3D FEM analysis for three structures of LTFRM without PMs on the mover

The results obtained show the flux density distribution in the three cases mentioned above. They are exposed in Fig. 9. It can be noticed that for the first two cases considered the flux density in the mover has a non uniform distribution, which is reflected in the value of the developed forces.

IV. CONCLUSIONS

In the paper a new structure of a linear reluctance transverse flux machine is presented. The machine having modular construction is easy to be manufactured and have relatively low production costs, since the price of the permanent magnets have a decreasing tendency. An important aspect concerning the construction of this machine is that besides SMC, for the iron poles can be used the classical steel sheets.

Its modular structure enables to easy adjust the motor's performances to the user's requirements without substantial changes in its basic structure. They are simple to control by unipolar current pulses.

ACKNOWLEDGEMENTS

The work was possible due to the support given by the Romanian National Council of Scientific Research in Higher Education under grant A27702/2005, theme A13, CNCSIS code 769 and grant TD27702/2005, theme TD4, CNCSIS code 257 (both grants in development). The authors should like to sincerely thank this way for the financial support.

REFERENCES

[1] Viorel, I.A, Henneberger, G., Blissenbach, R., Löwenstein, L., "*Transverse flux machines. Their behaviour, design, control and applications*," Mediamira, Cluj (Romania), 2003.

[2] Szabó, L., Viorel, I.A., *"An Integrated CAD Environment for Designing and Simulating Double Salient Permanent Magnet Linear Motors”,* Proceedings of the International Conference on Power Electronics, Drives and Motion (PCIM), Nürnberg, 2001, vol. Intelligent Motion, pp. 417-422.

[3] Popa, D.C., Iancu, V., Viorel, I.A., Szabó, L., *"C.A.D. of Linear Transverse Flux Motos,",* Annals of the Polytechnic Institute of Iaşi, vol. LI (LV), fasc. 5, Electrotechnics, Energetics and Electronics, 2005, pp. 79-84.

[4] Szabó, L., Popa, D.C., Iancu, V., *"Compact Double Sided Modular Linear Motor for Narrow Industrial Applications",* Proceedings of the 12th International Power Electronics and Motion Control Conference (EPE-PEMC '2004), Portoroz (Slovenia), in print.

[5] Szabó, L., Viorel, I.A., Chişu, I., Kovács, Z., *"A Novel Double Salient Permanent Magnet Linear Motor*Ţ, Proceedings of the International Conference on Power Electronics, Drives and Motion (PCIM), Nürnberg (Germany), vol. Intelligent Motion, 1999, pp. 285-290.

[6] Szabó, L., Viorel I.A., Iancu V., Popa, D.C., *"Soft Magnetic Composites Used in Transverse Flux Machines",* Oradea University Annals, Electrotechnical Fascicle, 2004, pp. 134-141.

[7] Viorel I.A., Szabó L., "*Hybrid Linear Stepper Motors*," Mediamira, Cluj (Romania), 1998.

[8] Dubois, M.R., "*Optimized Permanent Magnet Generator Topologies for Direct-Drive Wind Turbines*," Ph.D. Thesis, TU of Delft, Holland, 2004.

[9] Szabó, L., Viorel, I.A., Szépi, I., *"Linear and Planar Variable Reluctance Motors for Flexible Manufacturing Cells*”, Advances in Electrical and Electronic Engineering (Slovakia), no. 2, vol. 3, 2004, pp. 39-42.

[10] Szabó, L., Viorel, I.A., Dobai, B.J., Szépi, I., *"Optimal Trajectory Generation for a Modular Planar Motor Used in Flexible Manufacturing Systems”*, Proceedings of the 11th International Power Electronics and Motion Control Conference (EPE-PEMC '2004), Riga (Latvia), 2004, on CD: A53272.pdf.