Linear Transverse Flux Motor for Conveyors

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1. Introduction

The transverse flux machines (TFM), introduced at the beginning of the 80's, are possible solutions for different applications requiring special machines [1]. The researches have focused until now mainly on rotary TFMs [2]. Here a new type of permanent magnets linear transverse flux reluctance machine is proposed. Such machine can be successfully applied for example in conveyor applications. The factors that influence the behaviour of the machine are also presented. Conclusions on the operating conditions of the machine are drawn.

2. The Proposed Linear Machine

The proposed motor is a variable reluctance machine. For easy manufacturing the machine has a modular structure, as presented in Fig. 1.
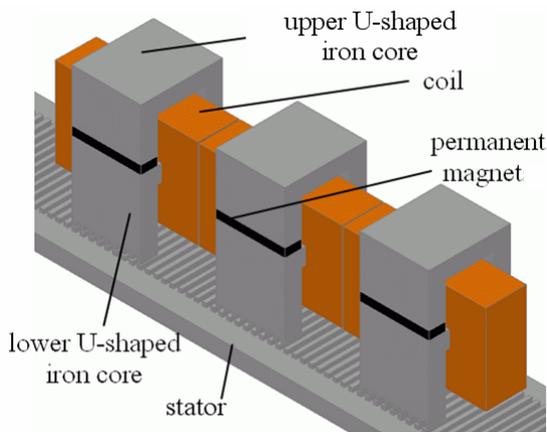
Fig. 1. The linear transverse flux reluctance machine with permanent magnets.

To work properly the modules have to be shifted one from each other by τ/N, where τ is the tooth pitch and N is the number of the modules. The step of the machine is given by the number of modules at a certain τ [3].

A module of the machine is built up of a U shaped iron core, two permanent magnets placed on the lower parts of the iron core poles. Another U shaped iron core closes the magnetic circuit, being placed over the permanent magnets. The two permanent magnets are magnetized in a way as to produce magnetic flux of the same direction. A concentrated coil, similar to one of the transformer, is placed on the core branch from the middle of the module.

The working principle of the machine is similar to that of a rotary TFM with permanent magnets in the stator and passive rotor.

When the module is passive (having its command coil un-energized) the flux generated by the permanent magnets closes mostly inside the mover's iron core, Fig. 2.
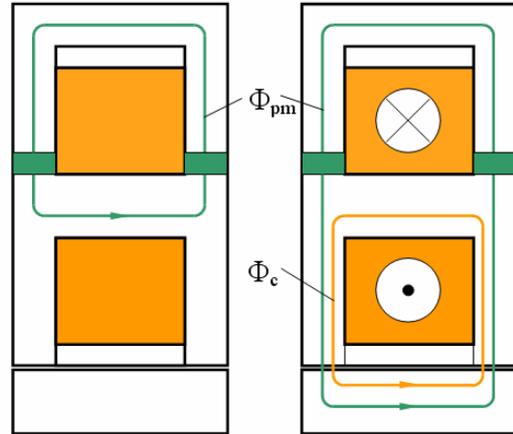
Fig. 2. The working principle of the permanent magnet linear transverse flux reluctance machine.

When the command coil is energized, the magnetic flux produced by the coil practically enforces the flux of the permanent magnets through the air-gap, generating this way tangential and normal forces. Due to the variable reluctance principle the mover will be placed in a position where the teeth of the active module are aligned with those of the stator [4].

The most important issue concerning this machine is, of course, the developed tangential force. This is influenced by: the length of the air-gap, the magneto-motive force of the coil and the active cross section of the iron core poles.

Next, the solutions found to increase the performances of the motor will be presented.

The air-gap length is an important parameter influencing the developed forces. It is ideal to be as small as possible in order to generate great forces, but its dimension is limited by the manufacturing possibilities and by the precision of the bearings.

The magneto-motive force of the coil is given by the current through a number of turns. Designing the coil it must be considered that it is supplied only periodically, hence greater current densities can be imposed as usually.

The variation of the force with the change of the two parameters presented above is non-linear [5].

The increase of the iron core active surface (at the same m.m.f.) will result in greater forces. However, the space available for the command coil will be diminished. Besides that, as proved in previous FEM analysis [3, 4, 5], the teeth are saturated. That's why the simple increase of the active surface is not a good solution.

A better solution is proposed by the authors. The improved linear machine is given in Fig. 3.

One module's structure without the coil wound on the core branch is shown in Fig 4.
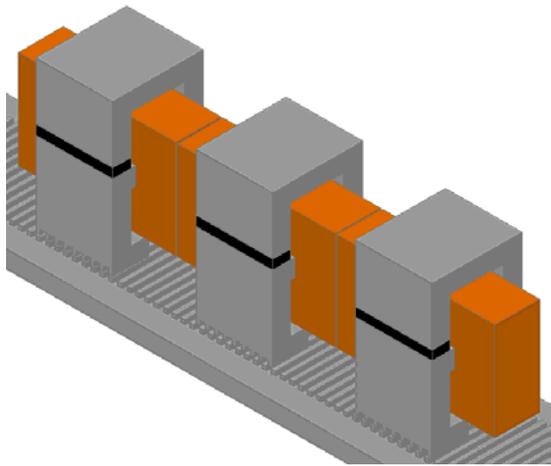
Fig. 3. The linear transverse flux reluctance machine with permanent magnets with enlarged teeth surface.

Fig. 4. Iron core with permanent magnets of a module of the linear transverse flux reluctance machine with enlarged teeth surface.

A design algorithm was performed specially for designing such machines. By its use several different machines had been designed, both with small teeth surface and with enlarged teeth surface.

A linear motor with small teeth surface was designed and analyzed by 3D FEM means.

The main dimensions of a single module of the machine's laboratory model are given in Fig. 5.
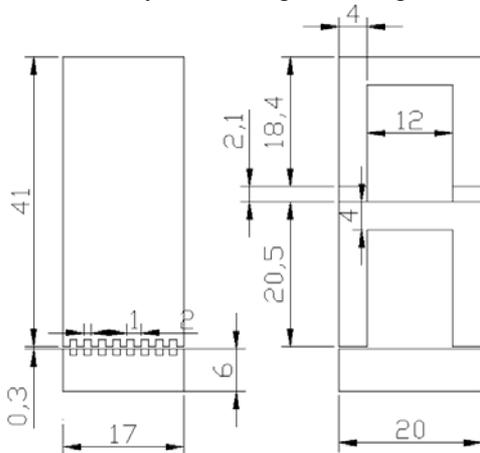
Fig. 5. Main sizes of linear TFM module with small teeth surface: a) lateral view; b) frontal view.

In Fig. 6 the variant with enlarged teeth surface is presented. It should be noticed that all the other geometrical dimensions are identical to the variant given above.
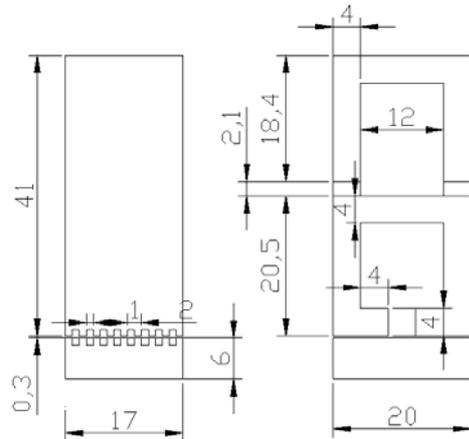
Fig. 6. Main sizes of linear TFM module with enlarged teeth surface: a) lateral view; b) frontal view.

3. The 3D FEM Analysis

By 3D FEM analysis two major issues were followed: the distribution of the flux density in he structure and the developed forces. Since only the coil of one module is supplied during a step displacement, it was enough to analyze only a single module and the portion of the stator under it.

First the distribution of the flux density shall be presented. Two important situations appear, as presented in Fig. 2: When the tooth of the module and the stator's ones are aligned and the coil is not supplied (passive module) and when the teeth are shifted and the coil gives a certain m.mf. Because the case of the passive module is quite identical for both variants of the machine, only the situation of the TFM with enlarged teeth surface is presented in Fig. 7.
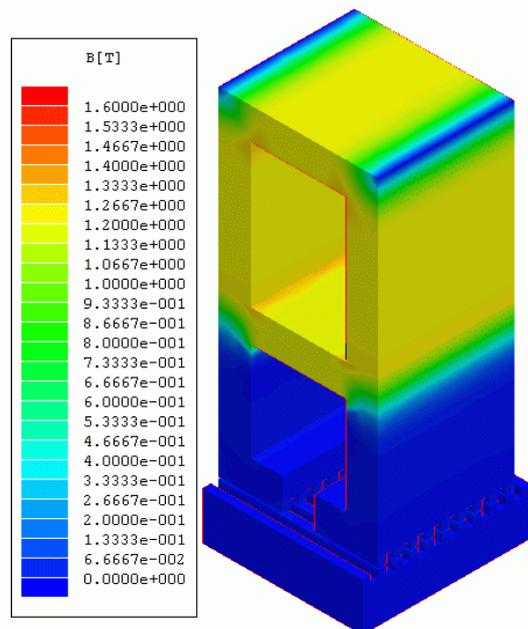
Fig. 7. Distribution of the flux density in a passive module of the machine having

As mentioned above, in this case the flux of the permanent magnets closes almost entirely through the core branch. The tangential and normal forces are both almost nil.

The other important situation is when the coil is supplied in order to obtain the desired tangential force. The variants proposed here are three phase machines and they were chosen because of the easy implementation of the control strategy from the converters existing on the market. As explained previously, the shifting of one module's teeth from the stator one is of one third of the pole pitch (0.66 mm in this case). However the maximum force is obtained for the situation of a shifting of half of a tooth pitch. This is also the case presented in Fig. 8 for the two variants approached in this paper. The m.m.f. of the coil is in both cases is 220 ampereturns.

The peak value of the tangential force in the first case is of 2.5 N, while the maximum normal force is more than 10 times bigger, 32.8 N. In the second case, the peak tangential force is twice greater than for the previous situation, 5.25 N, and the maximum normal force is 69.65 N. It can be concluded that at the same m.m.f., for the variant with enlarged teeth a greater flux flows through the lower U-shaped poles, hence resulting greater forces.

In order to make a complete comparison of the developed forces by the two presented machines, the static characteristic − force versus displacement − was computed as well by 3D FEM analysis for both cases. In the FEM analysis the displacement on a tooth pitch was considered, several positions of the moving armature relatively to the stator being studied. The obtained values are given in Table 1 for the tangential forces, and respectively Table 2 for normal forces.

a) module with small teeth surface

b) module with enlarged teeth surface

Fig. 8. Distribution of the flux density in an active module

Table 1. Tangential forces computed in different positions of the mobile armature at different currents in the coil.

Shifting [mm]	TFM with small teeth surface [N]	TFM with enlarged teeth surface [N]
0	0	0
0.1	0.95	2
0.2	1.75	3.7
0.3	2.25	4.75
0.4	2.45	5.1
0.5	2.5	5.25
0.6	2.35	4.9
0.7	1.95	4.25
0.8	1.5	3.2
0.9	0.8	1.7
1	0	0.05

Table 2. Normal forces computed in different positions of the mobile armature at different currents in the coil.

Shifting [mm]	TFM with small teeth surface [N]	TFM with enlarged teeth surface [N]
0	32.8	69.65
0.1	32.2	68.45
0.2	31	65.5
0.3	29.35	61.8
0.4	27.5	57.55
0.5	25.7	53.65
0.6	23.95	50.25
0.7	22.4	47.25
0.8	21	43.85
0.9	20.05	42.5
1	19.8	42.1

In these tables the positions for which the forces were computed are considered relatively to the aligned position of the teeth from the mobile armature relatively to the stator ones. The first value, 0 mm, corresponds to the perfectly aligned teeth.

The last position, 1 mm, means the opposite situation, completely unaligned teeth. For an accurate characteristic the positions considered were from 0.1 to 0.1 mm on the length of the half tooth pitch.

The variation of the two forces versus the relatively displacement of the two armatures for the two variants given above are given in Fig. 9.

In both cases, as expected from other variable reluctance machines, the tangential force has a near sinusoidal variation. Its peak is obtained, as was mentioned before, at half of the tooth pitch.
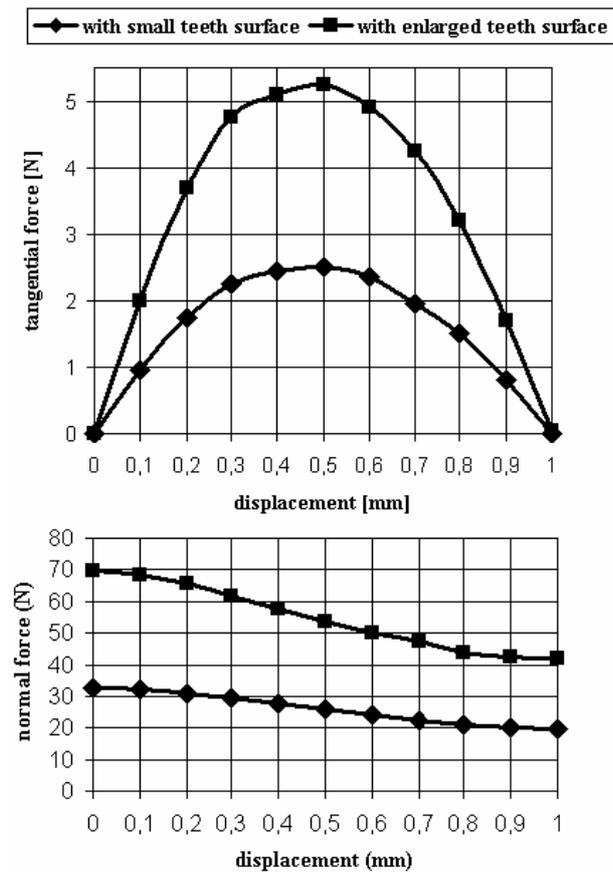
Fig. 9. The variation of the forces versus the module shifting for the two presented machines:
a) tangential force; b) normal force.

4. Conclusions

In the paper, a new structure of linear transverse flux motor was presented. The factors that influence the performance of the machine were analyzed.

A main advantage of this linear machine is that they can be built in very narrow variants, a frequent requirement in the industry. The cost of the machine is reasonable low due to the use of classical steel sheets.

They are simple to control by unipolar current pulses [7]. As being three phased machines, commercial power converters can supply them.

An other advantage of this machine is that the iron core can be made of classical steel sheets instead of using the costly SMC (Soft Magnetic Composites) often used for manufacturing TFM's [6, 8.

Hence the proposed linear motors seem to be a good solution for high precision positioning system used for conveying applications [9].

References

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

[2] G. Henneberger, and I.A. Viorel, "*Variable Reluctance Electrical Machines*", Shaker Verlag, Aachen (Germany), 2001.

[3] L. Szabó, D.C. Popa, V. Iancu, E. Kovács, F. Tóth, *On the Usefulness of Simulation in Designing a Permanent Magnet Modular Surface Motor for Advanced Mechatronic Systems*, Proceedings of the 2006 IEEE International Conference on Mechatronics (ICM '2006), Budapest (Hungary), pp. 88-93.

[4] L. Szabó, D.C. Popa, V. Iancu, "*Compact Double Sided Modular Linear Motor for Narrow Industrial Applications*", Proceedings of the 12th International Power Electronics and Motion Control Conference (EPE-PEMC '2006), pp. 1064 – 1069.

[5] D.C. Popa, V. Iancu, L. Szabó, "*Linear Transverse Flux Reluctance Machine With Permanent Magnets*", Proceeding of the International Conference on Transversal Flux Machines (ICTFM '2006), Changwon (South Korea), pp. 85 - 90.

[6] F. Marion, P. Meneroud, G. Magnac, "*Soft Magnetic Composite (SMC) and design of magnetic actuators*", Flux Magazine, N° 53 - January 2007 - CEDRAT - CEDRAT TECHNOLOGIES - MAGSOFT Corp - Adapted Solutions, pp. 14-16.

[7] L. Szabó, J.B. Dobai., "*Combined FEM and SIMULINK Model of a Modular Surface Motor*", Proceedings of the IEEE-TTTC International Conference on Automation, Quality and Testing, Robotics A&QT-R 2002 (THETA 13), Cluj-Napoca, tome I., pp. 277-282.

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

[9] I. Boldea, "*Linear Electromagnetic Actuators and their Control: A Review*", Proceedings of the EPE-PEMC '2002 Conference, Cavtat & Dubrovnik (Croatia), 2002, on CD: KEY-01.pdf.