MODULAR LINEAR TRANSVERSE FLUX RELUCTANCE MOTORS

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ABSTRACT

In the last decades different topologies of special electrical machines were studied. One of the most interesting machines belonging to this category is the transverse flux machine. The authors focused their study on the linear variant of this type of machine. Up today a small number of studies have approached the linear transverse flux machine, so the new perspective presented in this paper should be of real interest.

INTRODUCTION

The transverse flux machines (TFM) belong to the class of synchronous machines. Two major types were built until now: that with active rotor (having permanent magnets on it) and that with passive rotor (with or without permanent magnets on the stator) [1].

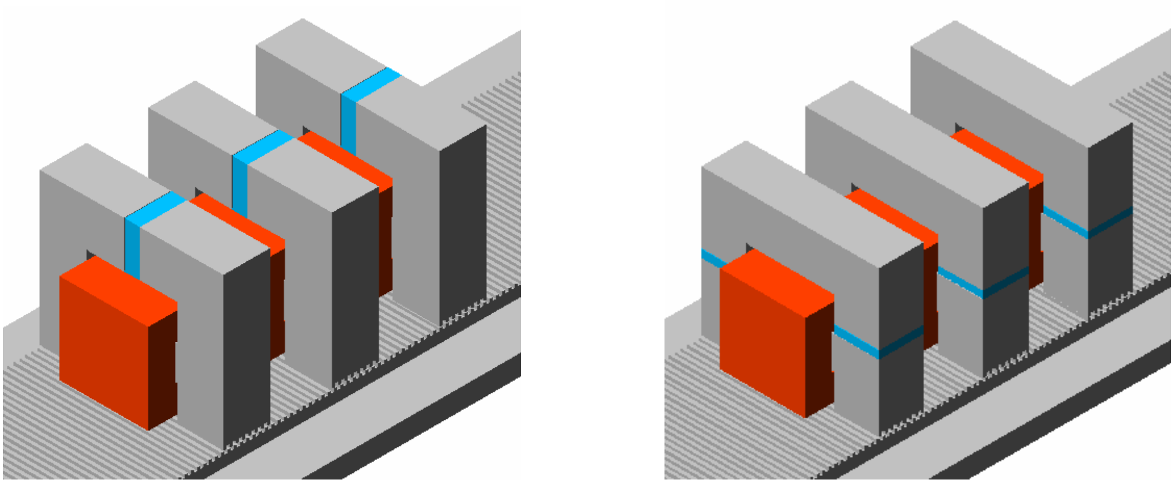
The paper deals with a new type of linear transverse flux machine. Two variants with permanent magnets were analyzed. Both of them operate based on variable reluctance principle.

LINEAR TRANSVERSE FLUX RELUCTANCE MOTOR

Until now several variants of linear transverse flux machines have been presented in the literature. The variant to be presented here was never cited in the literature.

Two TFM structures with permanent magnets will be proposed. The first variant was obtained from a rotary variant of TFM with passive rotor. The initial machine has a compact structure and belongs to the class of variable reluctance machines [2]. In order to control the motor an encoder on the shaft is required. For the linear variant a modular structure was proposed. To work properly its modules have to be shifted one from each other by τ/N, where τ is the pole pitch and N is the number of the modules. The displacement step of the machine is given by the number of modules. The simplest variant is the one with three modules because of the easy control possibilities. As in the case of the rotary machine a displacement encoder fixed on the mobile armature is necessary. In Fig.1.a) the structure of such a machine is shown [3].

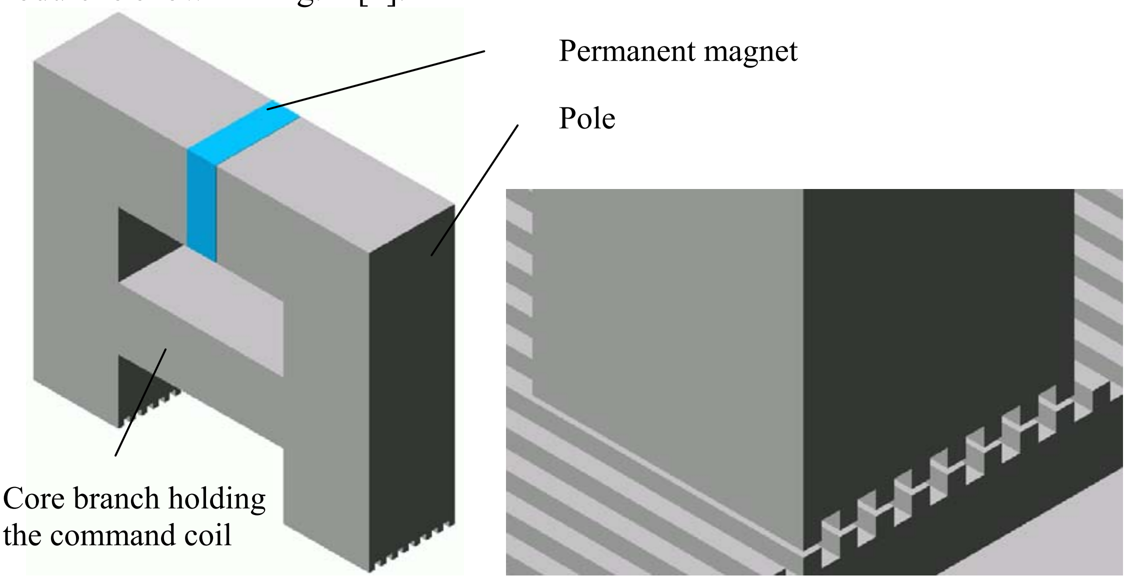
From the constructive point of view this structure presents some difficulties. The most important ones are related to the placement of the permanent magnet on the iron core and to the assembling of the coil on the iron core branch. Due to these shortcomings another variant of this machine was proposed having the same operation principle as the previous one. The difference consists of the position of the permanent magnets in the structure. The magnet from the first variant was replaced by two permanent magnets giving the same flux and having an equivalent magneto-motive force (mmf). The obtained structures are shown in Fig.1.b).



a) b)

Fig.1. Two structures of linear transverse flux reluctance machine
a) with one permanent magnet; b) with two permanent magnets

In the case of the first variant a module of the machine consists of 2 iron poles separated by a permanent magnet and a core branch which holds the command coil. The two poles have teeth on the direction of movement. The iron core of one module is shown in Fig. 2 [4].



a) b)

Fig. 2. The iron core of the mover: a) whole structure; b) toothed part.

Considering the second variant, the best method to build such modules seems to use two U-shaped iron cores. The coil used for each module is very similar with a transformer's one. The height of the two U-shaped iron cores is imposed by the height of the coil. The assembly of the whole structure with two permanent magnets is easier than in the first case. As it can be noticed, only one module generates forces at each time, the other N-1 ones being passive. The force developed has a similar variation to the SRM's torque, a greater number of modules producing smaller force ripples.

DESIGN AND 3D FEM ANALYSIS OF THE LINEAR TRANSVERSE FLUX RELUCTANCE MACHINES

The operating principles for the two structureS described above are identical. In both cases of the machine with permanent magnets two situations were considered: when the teeth of the mover are aligned with the ones from the stator and the winding in not supplied, respectively when the teeth from the two armatures are unaligned and the winding it is supplied. This represents in fact the operation principle of this machine, as shown in Fig. 3 [5].

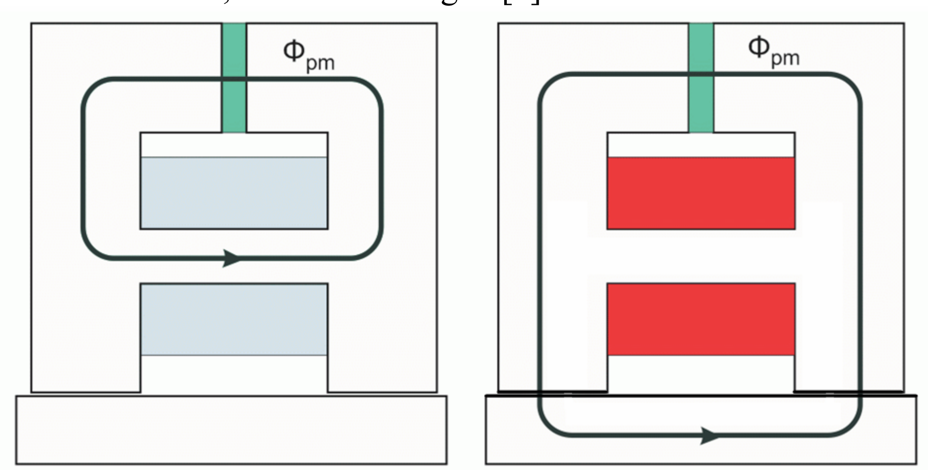


Fig. 3. The working principle of the linear machine.

When the module is passive (having its command coil un-energized) 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 coil practically enforces the flux of the permanent magnet through the air-gap, generating this way tangential and normal force. Energizing the command coil of one module its teeth will be aligned with the teeth of the platen.

The starting design data are: the required maximum tangential force F_{tmax}, the width of the running track w_s, the accuracy of the positioning (step length x_i), and the number of modules N. During the design procedure other geometrical and electrical quantities need to be imposed [6].

For the design of this machine the start point is the concept that the flux of the permanent magnet passes entirely through the air-gap and therefore the volume of the permanent magnet will be computed function of the desired tangential force and the flux density in the iron core and the one of the magnet. The active surface of the permanent magnet and its length are obtained.

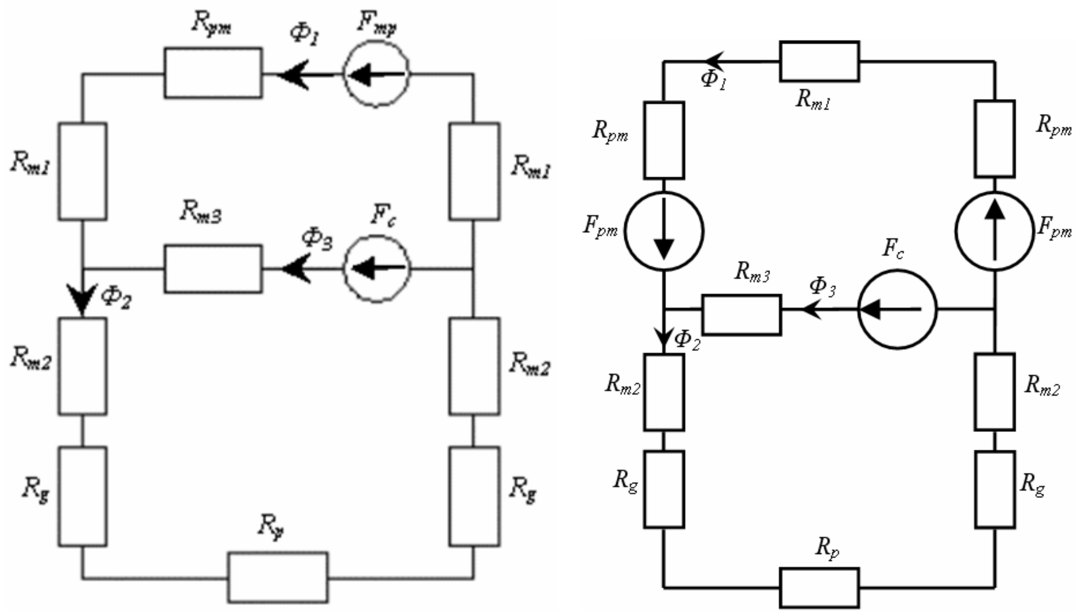
$$S_{pm_{\min}} = h_{pm} \cdot l_{pm} = k_p \, \frac{F_{t\max}}{B_p B_{pm}}; \quad w_{pm} = k_x \cdot \frac{B_r \cdot B_{pm}}{H_c \cdot (B_r - B_{pm})} \qquad (1)$$

where h_{pm}, l_{pm} and w_{pm} are the height, length, respectively the width of the PM, B_r is the residual flux density and H_c the coercive force of the selected PM. The dimensioning factors k_p, k_x are chosen based on previous design experiences [6, 7].

One of its dimensions, its length l_{pm}, can be chosen function of the teeth number of the machine. This can be subject of an optimization study. Function of the application requirements the machine can be either longer and less tall or shorter and taller. By knowing the value of the permanent magnet's width and its surface, its height can be easily determined. In this way the sizes of the permanent magnet are completely determined. At the same time the iron core's section results, as this is equal with the active surface of the permanent magnet.

The stator's length and height are imposed by the application of the motor to be used in. Its height is computed considering the flux in the circuit, the flux density in the stator and the surface crossed by the flux.

One of the most important problems of the designing procedure is related to sizing the winding. This is a simple concentrated coil which, when supplied, must cancel the permanent flux through the iron core branch and direct it through the lower parts of the mover poles and consequently through the air-gap. In order to do that, the equivalent magnetic circuit of the module and the corresponding part of the stator must be achieved [6]. In Fig.4 two magnetic circuits are presented: for the module with one and with two permanent magnets. Its elements are the magnetic reluctances of the iron core, of the core branch, of the platen and of the air-gap and the mmf of the permanent magnets and of the coil.



a) b)

Fig.4. The equivalent magnetic circuit of the two machines:
a) with one PM; b) with two PM's.

For the first case, the mmf of the coil is given by the relation:

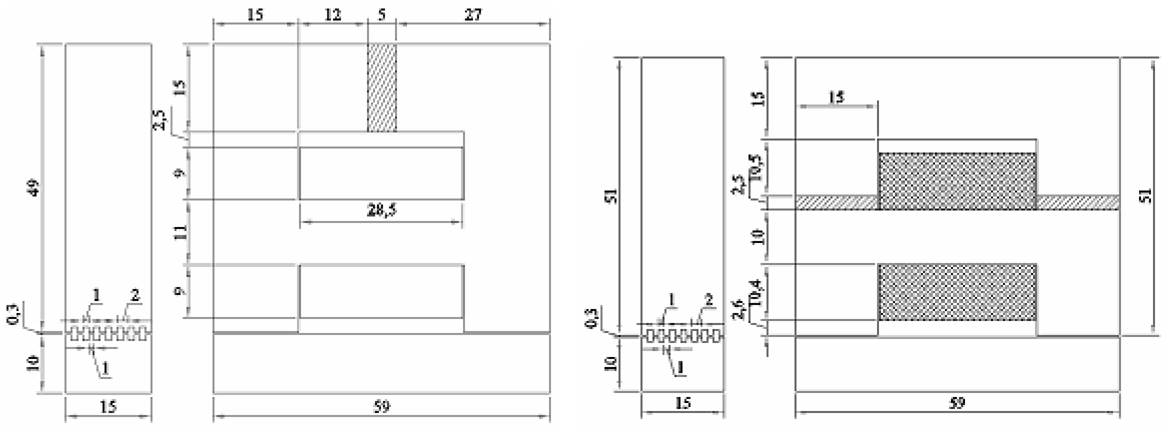
$$F_c = F_{pm} \frac{2R_{m2} + 2R_g + R_p}{R_{pm} + 2R_{m1} + 2R_{m2} + 2R_g + R_p} \tag{2}$$

For the second variant the, mmf of the coil results as:

$$F_c = 2F_{pm} \frac{2R_{m2} + 2R_g + R_p}{R_{pm} + 2R_{m1} + 2R_{m2} + 2R_g + R_p} \tag{3}$$

The height of the machine is function of the coil's height. In this way all the dimensions of the machine can be computed.

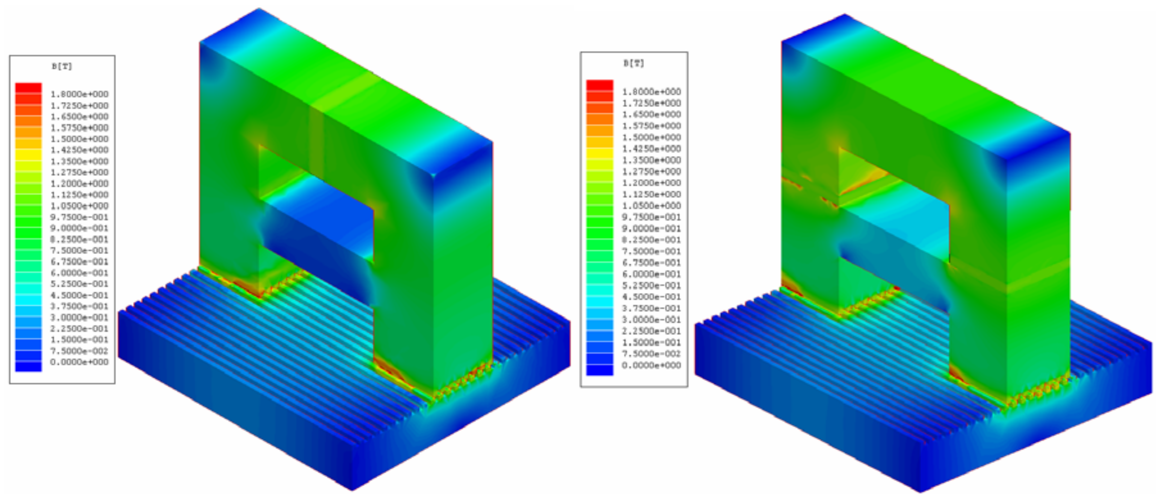
In order to prove the validity of the design algorithm a motor for each variant was designed. The algorithm described above was applied to design a linear motor having the following design data: F_{tmax}=5 N, w_s=59 mm, x_i=0.66 mm, N=3. The structure of these two linear machines was shown in Fig. 1. The main dimensions of the sample motors are given in Fig. 5.



a) b)

Fig.5. Lateral and frontal view of the proposed linear TFM's:
a) module with one PM; b) module with two PM's.

A comparison between the two structures was performed by 3D FEM analysis. The value of the coil's mmf in both cases is 380 Amperturns. With numerical analysis the developed forces were computed. For the variant with one PM the tangential force is of 5.4 N, and the normal force is of 56.06 N. For the variant with two PM's the tangential force is of 5.46 N, and the normal force is of 56.71 N. As it can be noticed the difference between the developed forces is minor. In both cases the normal force is about 10 times bigger than the tangential one.



a) b)

Fig. 6. The flux density distribution obtained via 3D FEM analysis:
a) module with one PM; b) module with two PM's.

CONCLUSIONS

Two variants of modular linear transverse flux reluctance machines were proposed here, both with permanent magnets. The operation principles were presented. The design principles given can be used also for dimensioning other similar machines. These motors are possible solutions for different conveyor systems. The main difference between the variants is related to the possibility of building the proposed machine. Different construction techniques for the analyzed motors were presented in the paper.

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