

## C.A.D. OF LINEAR TRANSVERSE FLUX MOTORS

BY

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**Abstract.** In this paper a new structure of the linear transverse flux machine will be presented. It is a combination of a hybrid linear stepper motor and of a linear transverse flux machine with permanent magnets. The design algorithm of the proposed structure will be presented in detail. Upon this algorithm a motor required by a specific application was designed. Several programming packages were used during the design procedure.

**Keywords:** transverse flux, stepper motor, variable reluctance, algorithm.

### 1. Introduction

The transverse flux motor (TFM) is a relatively newcomer in the class of the special electric machines. One of its major impediments is in fact its complicated construction [1]. Another significant aspect which must be taken into account when designing a TFM is that most of the prototypes already proposed use for their cores expensive soft magnetic composites (SMC), because these materials allow a three dimensional flux path [2]. These are the reasons which prevented the companies from having a mass production of this type of electrical machine.

In this paper a new structure of a linear TFM is presented. It has two important advantages: its design is rather simple and it can be built up of low cost materials (the mover of classical steel sheets and the platen of massive iron), avoiding the use of expensive SMC.

### 2. Structure of the Proposed Linear TFM

The proposed linear TFM resulted by combining a hybrid linear stepper motor [3] and a linear variant of the TFM with permanent magnets (PM) on the stator and passive rotor [2]. The proposed structure, shown in Fig. 1a, is built up by modules. A variant with three modules was selected because of the easy implementation of the control strategy on general purpose three-phase power converter. A module without coil is given in Fig.1.b. Each module has two teathed poles and a PM between them. The command coil is placed on a core branch in parallel with the PM.

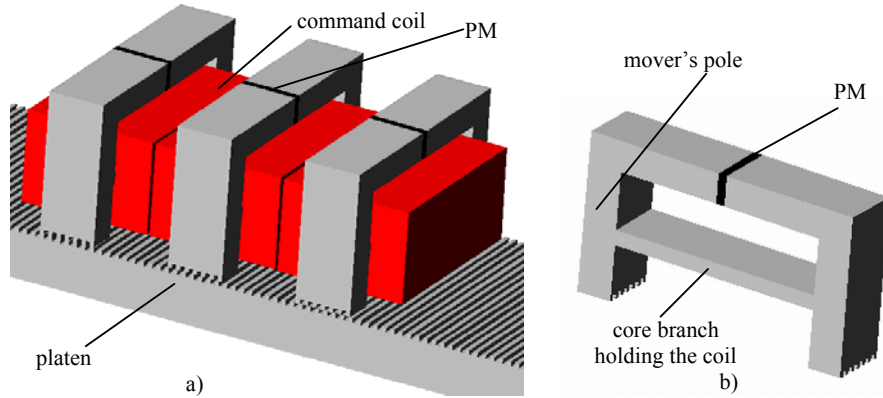


Fig.1. a) The basic structure of the proposed linear TFM; b) A module of the machine

In fig. 2 the working principle of the machine is presented. In fig. 2a the flux path in a single module is shown when its winding is not energized. In this case the flux generated by the PM closes mostly inside the mover's iron core. When the winding is energized, fig. 2b, the flux produced by the winding practically enforces the PM's flux through the air-gap, generating this way tangential and normal forces [4].

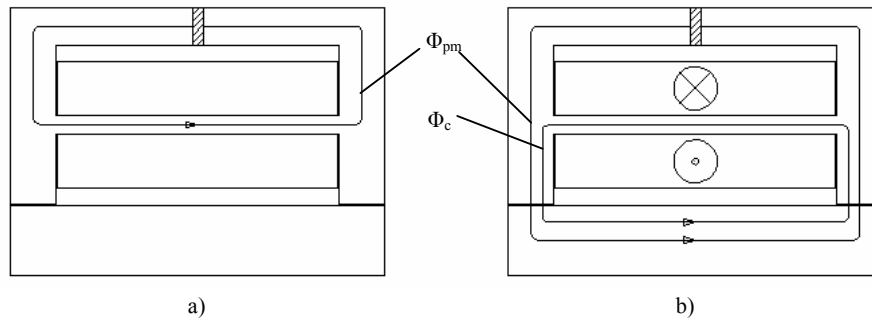


Fig.2. The working principle of the proposed linear TFM; a) not excited coil; b) excited coil

The proposed structure is in fact a variable reluctance machine. 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 a continuous linear movement of any direction can be assured [1].

### 3. The Design Algorithm for the Presented Structure

As the structure of the proposed linear TFM is not very complicated, its design algorithm is not too complex either.

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.

The tooth pitch can be computed upon the given step length and number of modules ( $\tau = N \cdot x_i$ ).

First of all the type of the PM and the working point on its demagnetizing curve ( $B_{pm}$ ,  $H_{pm}$ ) have to be selected. Also in this stage has to be specified the flux densities in the in the mover core  $B_p$  and in the platen  $B_s$ .

Next the dimensions of the PM must be computed. Its minimum active surface, respectively its width are given by:

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

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 two dimensioning factors  $k_p$  and  $k_x$  are chosen based on similar design experiences [1, 4].

The length of the PM is imposed by the width of the running track  $w_s$ . As the mover poles are toothed in the direction of the PM's length a supplementary condition must be imposed for the length of the PM:

$$l_{pm} = Z \cdot (l_t + l_s) + l_t; \quad Z \in N \quad (2)$$

where  $Z$  is the number of teeth,  $l_t$  the tooth length and  $l_s$  slot length.

The tooth and respectively the slot length have to be chosen in such a way as the  $0,32\tau \leq l_s \leq 0,5\tau$  condition to be taken into account.

The magnetic flux given by the PM is:

$$\Phi_{pm} = B_{pm} \cdot S_{pm} = B_{pm} \cdot h_{pm} \cdot l_{pm} \quad (3)$$

The length of the pole  $l_p$  has to be equal to the length of the magnet  $l_{pm}$ . Its width  $w_p$  can be computed from the magnetic flux which crosses the active surface of the pole:

$$w_p = \frac{\Phi_{pm}}{B_p \cdot l_{pm}} \quad (4)$$

One of the most sensitive stages of the motor's design is the sizing of the core branch on which the command coil is placed. When the module is inactive, all the flux generated by the permanent magnet has to pass through this core

element. While the command coil is energized the command flux produced has to direct the entire permanent magnet flux to pass through the poles and air-gaps. Its width is also imposed by the width of the running track  $w_s$ :

$$w_b = w_s - 2w_p \quad (5)$$

Next the platen's dimensions were computed. Its width  $w_s$  was prescribed as a design data. The length of the platen is imposed by the requirements of the application the motor to be used. The platen's active surface  $S_s$  is given by the flux passing through, and by the flux density in the platen  $B_s$  established earlier:

$$S_s = \frac{\Phi_{pm}}{B_s} \quad (10)$$

Hence the height of the platen can be easily calculated as:

$$h_s = \frac{S_s}{w_s} \quad (11)$$

In order to compute the MMF of the command coil,  $F_c$ , the equivalent magnetic circuit of a module and of the platen segment under it has to be built up as shown in fig. 3 [5].

As the main dimensions of the magnetic cores are known at this time the magnetic reluctances of the equivalent magnetic circuit can be easily computed. For the reluctance of the air-gap  $R_g$  the relative position of the mover module from the platen must be taken into account [3].

It was imposed as when the coil is energized the magnetic flux in the core branch under the magnet ( $\Phi_3$ ) to be nil, hence all the flux generated by the PM to be forced through the air-gap. This condition is fulfilled when:

$$F_c = F_{pm} \frac{2R_{m2} + 2R_g + R_p}{R_{pm} + 2R_{m1} + 2R_{m2} + 2R_g + R_p} \quad (6)$$

The final sizing of the command coil follows the steps known from the computation of the transformer's windings [5].

Finally having all the sizes of a mover module the distance between two neighbored modules was established as:

$$l_{pp} = k\tau + t_s + \frac{\tau}{3} > 2 \cdot l_c; \quad k \in N \quad (7)$$

where  $l_c$  is the length of the coil.

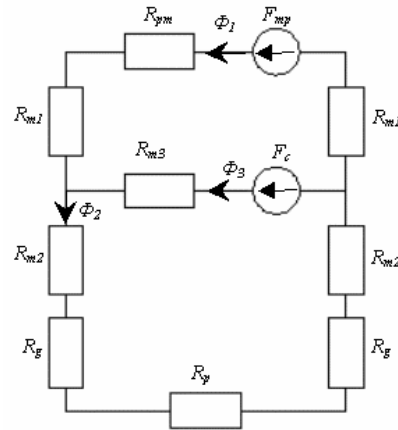


Fig.3. The equivalent magnetic circuit

All the sizing equations were implemented in MathCAD, a versatile computation environment for designing electrical machines.

#### 4. Design Example

The design algorithm described above was applied to design a linear motor having the following design data:  $F_{max}=15$  N,  $w_s=59$  mm,  $x_i=0.66$  mm,  $N=3$ . In Table 1 the main characteristics of the designed linear TFM are given.

**Table 1:** Main data of the designed motor

Teeth number per pole $Z$	6	Length of the PM $l_{pm}$	13 mm
Height of the mover $h_m$	31 mm	Height of the PM $h_{pm}$	6 mm
Height of the platen $h_s$	11 mm	Width of the PM $w_{pm}$	1.7 mm
Tooth width $l_t$	1 mm	Turns number of the command coil $w$	520
Slot width $l_s$	1 mm	Rated command current $I_c$	1 A
Width of the mover's pole $w_p$	7.2 mm	Height of the coil $h_c$	8.5 mm
PM residual flux density $B_r$	1.2 T	Height of the core branch $h_b$	3 mm
PM coercive force $H_c$	910 kA/m	Air-gap length $g$	0.1 mm

The topology of this linear machine was shown in Fig. 1. The main dimensions of the sample motor are given in Fig. 4.

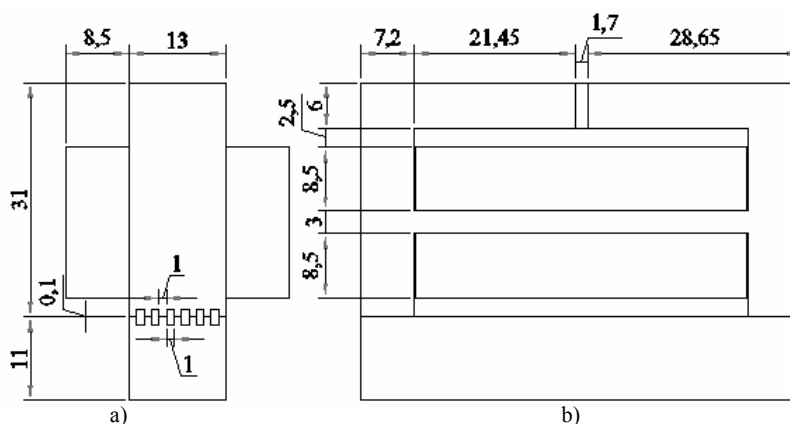


Fig.4. Main sizes of proposed linear TFM module: a) lateral view; b) frontal view

## 5. Conclusions

The linear motor structure proposed here may be of real interest because very few linear variable reluctance TFMs are presented in the literature.

The modular construction of the motor is flexible. Several motors of different forces and step lengths can be built up of similar modules with that presented in the paper.

From the various advantages of the proposed motor over the other linear TFMs it should be stated out here only a few. It does not require expensive and hard-to-process materials for its construction, and its width do not exceed the width of the running track. Hence it can be used also in narrow places.

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## REFERENCES

1. Viorel, I.A., Henneberger, G., Blissenbach, R., Löwenstein, L., *Transverse flux machines. Their behaviour, design, control and applications*, Mediamira Publisher, Cluj-Napoca (Romania), 2003.
2. Szabó L., Viorel I.A., Iancu V., Popa D.C.: *Soft Magnetic Composites Used in Transverse Flux Machines*, Oradea University Annals, Electrotechnical Section, 2004, pp. 134-141.
3. Viorel I.A., Szabó L., *Hybrid Linear Stepper Motors*, Mediamira Publisher, Cluj-Napoca (Romania), 1998
4. Szabó L., Viorel I.A., Chişu I., Kovács Z.: *A Novel Double Salient Permanent Magnet Linear Motor*, Proc. of the International Conference on Power Electronics, Drives and Motion (PCIM), Nürnberg, 1999, vol. Intelligent Motion, pp. 285-290.
5. Popa, D.C., Iancu, V., Viorel, I.A., *On the Transverse Flux Linear Motor Design*, accepted paper for the SIELMEN '2005 Conference, Chişinău (Moldova).
6. Popa, D.C., Iancu, V., Viorel, I.A., *A Comparison Between Different Transverse Flux Motor Variants*, Oradea University Annals, Electrotechnical Section, 2005, in print.

### PROIECTAREA ASISTATĂ DE CALCULATOR A MOTOARELOR LINIARE CU FLUX TRANSVERSAL (Rezumat)

*Se prezintă un nou tip de motor liniar cu flux transversal obținut prin combinarea motorului hibrid liniar pas cu pas modular și a unui motor cu flux transversal cu magneți permanenți în armătura mobilă și cu armătură fixă pasivă. După prezentarea principiului de funcționare și a structurii de bază a unui astfel de motor se expune detaliat algoritmul de proiectare elaborat. Pentru exemplificare s-a proiectat o mașină folosindu-se date concrete impuse de o posibilă aplicație.*