DYNAMIC SIMULATION OF A NOVEL HYBRID LINEAR STEPPER MOTOR BY MEANS OF MATLAB/SIMULINK®

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ABSTRACT

The main advantage of linear motors is that they do not turn the electric energy supplied into a rotary movement, but convert it directly to a linear movement. The direct coupling of the mover armature to the load provides several performance benefits in addition, as high speeds, high precision, no backlash, high stiffness and fast response and settling times. In these circumstances it is interesting the study of a novel high performance direct drive modular hybrid linear stepper motor. The results obtained via computer simulation performed using Matlab/SIMULINK® environment stand by to sustain the pertinence of the motor configuration in study.

1. INTRODUCTION

Direct-drive linear motors have the motor and load directly and rigidly connected. Gone are the ballscrews, gear trains, belts, and pulleys. All of these create advantages in simplicity, efficiency, and positioning accuracy. Especially the acceleration available from these motors is remarkable compared to traditional motor drives that convert rotary to linear motion.

As it was pointed out in several previous papers [1, 2] the well known and wide-utilised hybrid linear stepper motor has some disadvantages [2, 3]. In any position of the mover one of its pole is generating a significant breaking force, diminishing the total tangential force of the motor. This way its global efficiency is reduced. Beside this the magnetic fluxes passing between the mover and the platen through the poles give rise to a very strong normal force of attraction between the two armatures. The greatest normal force is generated of the same pole that is producing the above mentioned breaking tangential force.

In order to eliminate these disadvantages a novel modular hybrid linear stepper motor was proposed [2, 3]. The cross section of this motor is presented in Figure 1.

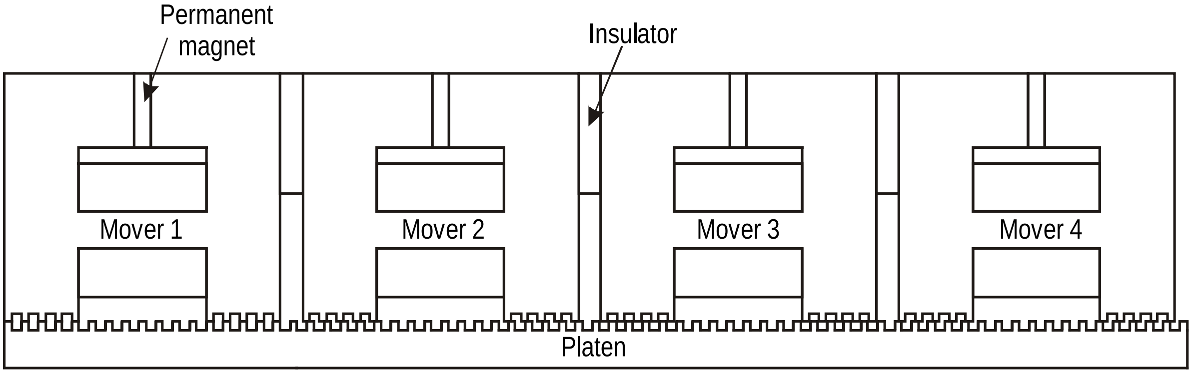

Figure 1. The modular hybrid linear stepper motor

The mover of the motor in discussion is built up of four independent modules, displaced relatively by the quarter of the teeth pitch. Each module has two pole pieces, a permanent magnet and a command coil. The command coil is placed on a core branch in parallel to the permanent magnet. The two poles of the module are spaced in a way as if the teeth of one pole are aligned with the teeth of the platen, than the teeth of the other pole are also aligned with the platen's teeth. The platen is an equidistant toothed bar of any length fabricated from high permeability cold-rolled steel. The toothed structures on both armatures have the same fine teeth pitch. An air bearing system maintains the required air-gap between the two armatures during the mover's travel along the platen, providing straight, stiff and cog-free motion at low resolutions, assuring virtually unlimited life for the motor.

Like the classical hybrid linear stepper motor, this motor variant is also operating under the combined principles of variable reluctance and of permanent magnet motors [4]. When the command coil of the module is un-energised, the magnetic flux generated by the permanent magnet flows through the core branch under the magnet, because its magnetic reluctance is much more smaller than the reluctance of the air-gap. Thus the inactive mover module produces negligible tangential and normal forces. This is the main advantage of the novel motor structure. Beside this, due to the permanent magnet the motor has two other main benefits: it has high force output per unit size and low heat generation.

When the command coil is energised, the magnetic flux of the permanent magnet is forced to flow through the air-gap. The active mover module will attempt to align its teeth with the platen teeth by generating a significant tangential force in a manner as to minimise the air-gap magnetic energy. All the developed force is applied directly to the load and the performance achieved is independent of the length of the platen.

An incremental displacement of any sense may be obtained by applying selectively the current pulses to the four command coils. For this motor structure four steps result in motion of one tooth pitch interval.

The modular hybrid linear stepper motor is easily controlled by digital commands. It finds good usage in machine tools, semiconductor production, and other precision processes, where fast and accurate displacements under heavy loads are required. Tomorrow's applications are wide open.

2. THE MATHEMATICAL MODEL

The mathematical model used to analyse the dynamic performance of the above-presented motor is an analytical coupled circuit-field model, presented in several previous works [4, 5]. The block diagram of the complete model is presented in Figure 2.

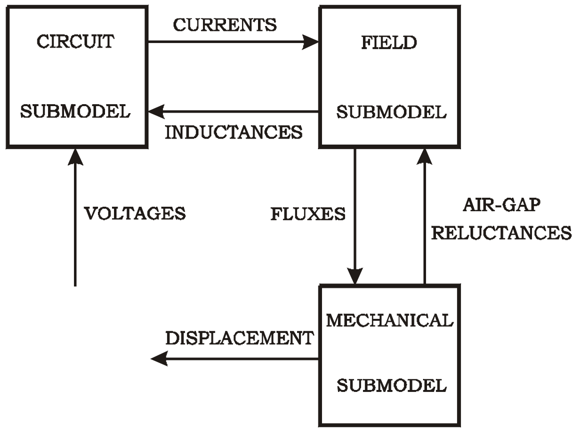

Figure 2. The block diagram of the mathematical model

The model takes into account the complex toothed configuration, the magnetic saturation of iron core parts and the permanent magnet operating point changes due to air-gap variable reluctance and control amperturns, too.

In order to reduce the amount of computations the circuit submodel was considerable simplified by assuming that ideal current generators feed the command coils.

In the flux submodel the magnetic flux linkage through the motor is computed taking into account the modifications of the air-gap reluctances due to the mover's displacement. The computations are based on a simply to compute equivalent magnetic circuit of the motor, shown in Figure 3. This method is not the most accurate one, but it needs relatively short computation times.

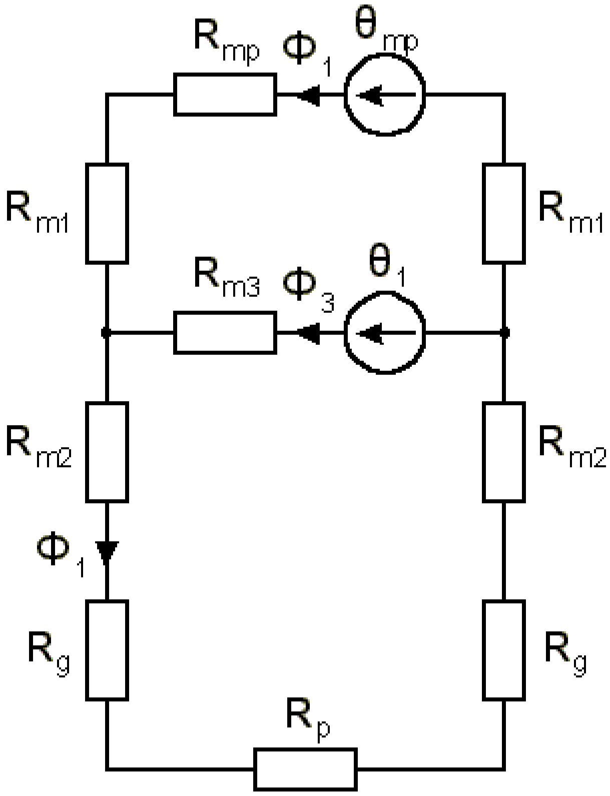

Figure 3. The equivalent magnetic circuit of one mover module

The third part of the modular hybrid linear stepper motor's mathematical model is the mechanical submodel. In this module the developed forces are computed from the magnetic fluxes [4]. By solving the movement equation of the motor the mover's speed and displacement can be obtained.

The coupled circuit-field model can not be solved analytically. The computational process consists of a simultaneous iterative calculation of the different equations of the three subsystems and can be performed only by using high-speed computers.

The above-presented model is very helpful in the study of the dynamic regime of the motor and also in verifying the motor's design and in elaborating an optimal control strategy.

3. COMPUTER SIMULATION

The computer simulation of the motor was performed using the Matlab/SIMULINK® environment. Matlab is a visualisation and numerical program package doing any kind of numerical computation. The goal of Matlab is to enable scientists to use matrix-based techniques to solve problems, using state-of-the-art code, without having to write programs in traditional languages like C and Fortran. More capabilities have been added as time has passed, several new commands, and very fine graphics capabilities. There are also many different toolboxes available, which extend the basic functions of Matlab into different application areas. One of these wide-used toolboxes is SIMULINK, a powerful environment for rapidly modelling, analysing and simulating an extraordinarily wide variety of physical systems. It provides a graphical user interface for constructing block diagram models of dynamic systems. A large library of blocks is provided, which makes possible to model any system without having to write a single line of simulation code.

The SIMULINK model of a mover module is presented in Figure 4.

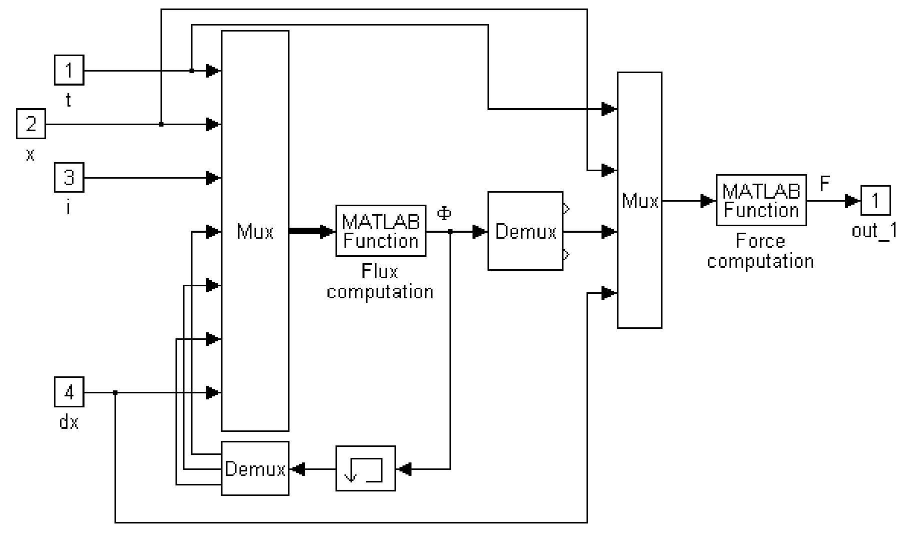

Figure 4. The model of a mover module

All the blocks contained in Figure 4 are grouped together into a single block, shown in Figure 5. The input signals in the block are the time (*t*), the displacement (*x*), the command current (*i*) and the relative displacement of the module's central axes to the reference axes (*dx*). The block generates as output a signal vector having two components: the tangential and the normal force developed by the two poles of the mover module.

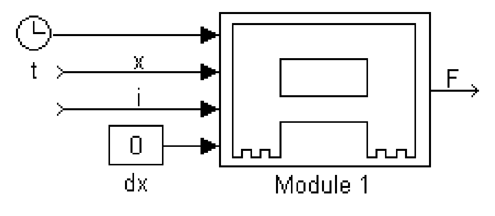

Figure 5. The grouped block

Inside the block two MATLAB functions are called. The first, *fluxcomp.m* computes the magnetic fluxes through the mover, based on the equivalent magnetic circuit presented in Figure 3. The required inputs for the program are beside those mentioned above the flux values from the previous time step provided by a *Memory*-type block included in the diagram in order to break the algebraic loops. An other m-type function file (*forcecomp.m*) computes the forces generated by the mover module. This function uses as inputs beside the magnetic fluxes the time, the mover's position and the relative position of the pole's axes.

The complete scheme of the simulation program is presented in Figure 6.

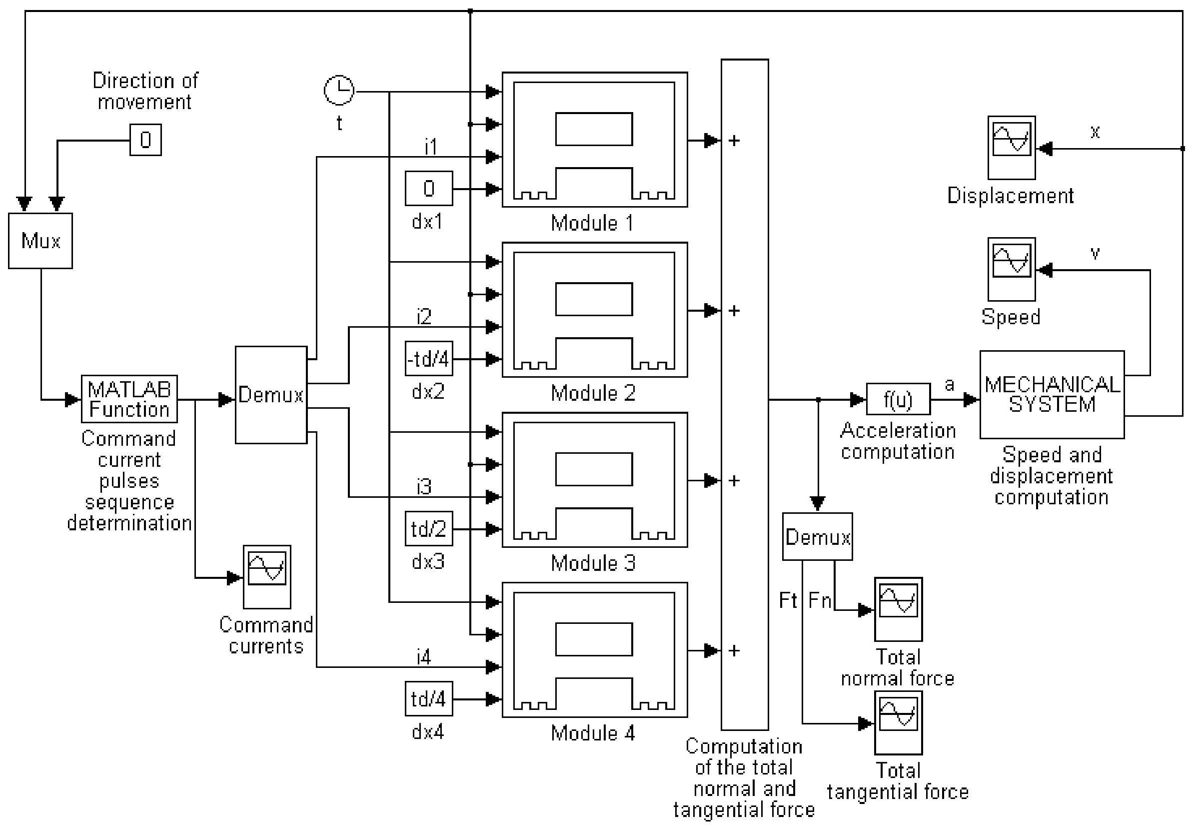

Figure 6. The main scheme of the simulation program

The SIMULINK program for simulating the modular hybrid linear stepper motor is well organised in order to be easy to understand and use. It is composed of several blocks. The main part of the motor consists of four blocks as that shown in Figure 4, each modelling a mover module. Only the relative displacements of each module's central axes to the reference axes (*dx1÷dx4*) are different. The necessary sequence of the command current pulses is set by a separate Matlab function, named *current.m*. This determines the command coil to be energised function of the required direction of displacement and the actual position of the mover. As outputs of this function the four command currents are obtained.

The tangential and normal forces computed in each block corresponding to a mover module are added in order to obtain the total values of these forces. Using the total forces in addition to the mover's mass and the friction coefficient the acceleration of the mover is computed in a *Fcn*-type SIMULINK block.

By integrating the acceleration of the mover the speed and displacement can be obtained. A simple SIMULINK block implements the mechanical system's model. The internal structure of this block is shown in Figure 7.

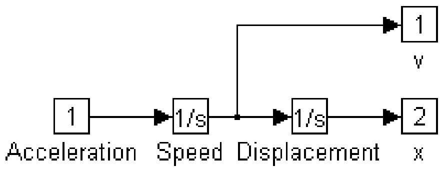

Figure 7. The internal structure of the *Mechanical System* block

Several *Auto-Scale Graph*-type blocks complete the simulation program in order to obtain all the required results graphically, in the simplest way to evaluate them.

Next the simulation results for a four step (2 mm) long movement of the motor will be presented. The most significant plots versus time are presented in Figure 8.

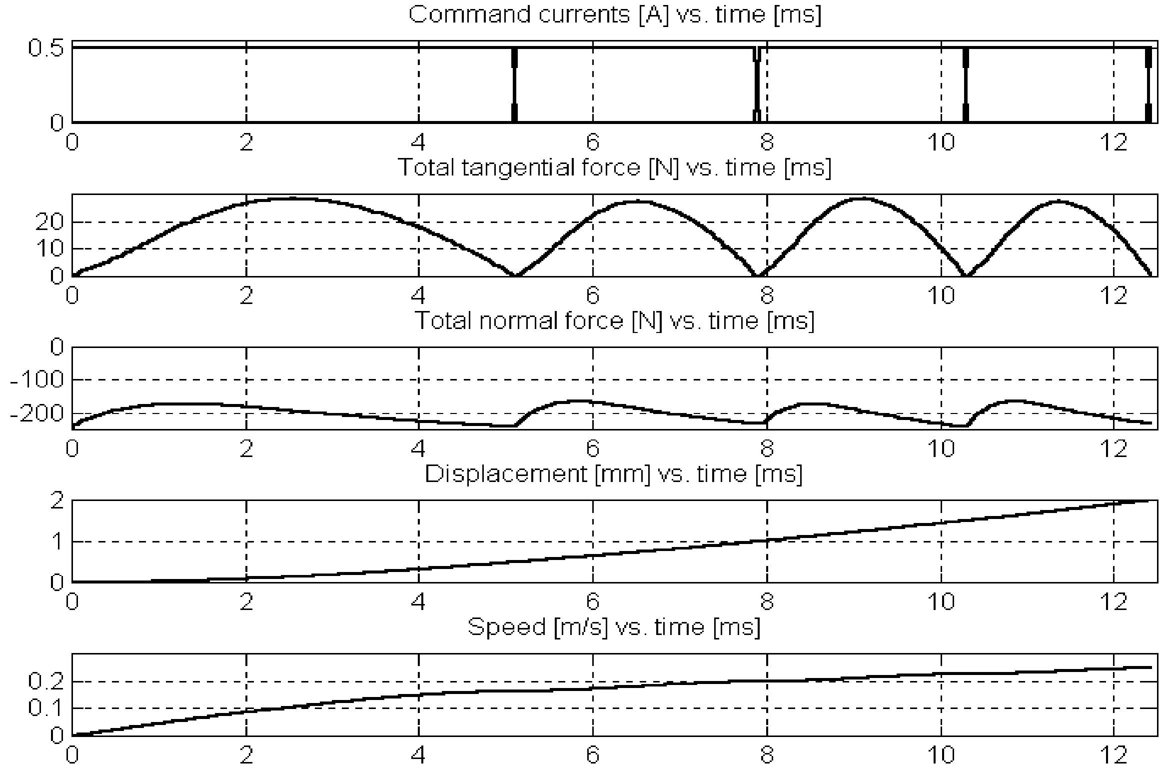

Figure 8. Results of simulation

As it can be observed all the results agree with the theoretically inspected ones. The total tangential force is nil in the intermediate equilibrium positions. The total normal force is much more greater than the total tangential force. During the considered movement the speed is increasing, thus the frequency of the command current pulses is also increasing and the displacement is varying near linearly.

All these highlight the pertinence and usefulness of the elaborated mathematic model of the modular hybrid linear stepper motor. The model and the simulation program can be used in the optimisation process of the design and in elaborating an efficient control strategy in order to improve the performances of the motor in study.

5. REFERENCES

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