

COUPLED SIMULINK-SIMPLORER MODEL OF A MODULAR HYBRID LINEAR STEPPER MOTOR

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ABSTRACT

The modular hybrid linear stepper motor in discussion has improved performances due to its novel construction. This linear motor can be one of the best choices for industrial applications where fast and accurate linear motions under heavy loads are required.

In this paper a coupled simulation program of this motor will be presented. The basic part of the model is built up in SIMULINK. The forces of the motor are not computed at each time step. They are taken from two look-up tables containing the static characteristics of the forces, computed using MagNet 6.0 FEM-based magnetic field analysis program. The power converter's model was made in SIMPLORER, a widely used simulation program in the field of power electronics. The converter units were coupled into SIMULINK by the Sim2Sim link. This way all the parts of the model were implemented in the most suitable platform for each of them.

The obtained results are in good accordance with the theoretical expectations and with the results of analytical computations. This means that the overall performances of the simulation program are quite good. Therefore the idea of coupling units built-up in different simulation platforms into a single simulation program could be also applied for simulating other types of electrical machines.

INTRODUCTION

A mathematical model of an electric machine is based on a theoretical approach and can be used for easy performance prediction and control without prototyping. To be useful the model must be realistic and yet simple to understand, easy to manipulate and implement.

The development of a practical model is not easy, because the above mentioned requirements are conflicting. Therefore a skilful mathematical model of a certain electrical machine can be very useful for prediction of its behaviour both in transient and steady state regime, and for testing several control schemes [1].

In this paper a coupled simulation program of a modular hybrid linear stepper motor is presented. The blocks of the simulation programs were implemented in several different simulation platforms (SIMULINK, SIMPLORER and MagNet); each one of them widely used in its field. Hence the main advantages of each platform were exploited, and the global efficiency of the entire simulation program is almost as high as possible.

THE THREE-PHASE MODULAR HYBRID LINEAR STEPPER MOTOR

The three-phase modular hybrid linear stepper motor (Fig. 1) was previously presented in several papers [2].

It is a direct-driven linear motor, which can replace rotational to linear movement translator devices. Therefore it is simple, efficient and has high positioning accuracy.

The mover of the motor is a single stack composed of three modules (Fig. 2). Each module has a permanent magnet, two salient teathed poles and a command coil. If the command coil is not energised, the flux generated by the permanent magnet passes through the core branch parallel to the magnet due to its smaller magnetic resistance. In this case there is no significant force produced. If the coil is energised, the command flux produced by it directs the flux of the permanent magnet to pass through the air-gap and to produce significant forces. Due to the tangential component of the force the moveable armature moves one step minimising the air-gap magnetic energy.

The modular linear motor eliminates several disadvantages of the "classical" hybrid linear stepper motors [2]. Due to these benefits it is one of the best choices for industrial applications where fast and accurate linear motion under heavy loads are required.

THE SIMULATION PROGRAM OF THE MOTOR

The main part the coupled simulation program is implemented in MATLAB/SIMULINK. As it is well known, this environment is one of the best suited for the dynamic simulation of electrical machines.

The primary window of the simulation program is given in Fig. 3. As it can be seen, it is built up in a modular manner. All the components of the linear drive system can be clearly distinguished in the model. This way high transparency was assured for the users. The program calls several MATLAB functions, e.g. for the setup (when the motor's main parameters are loaded from data files) or for the final plotting of the results. All the benefits of MATLAB (easy to write program lines, advanced graphical

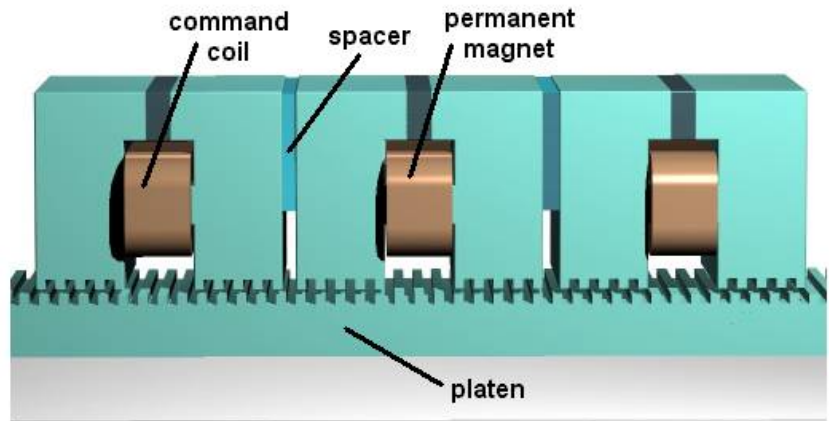


Fig. 1. The three-phase modular hybrid linear stepper motor

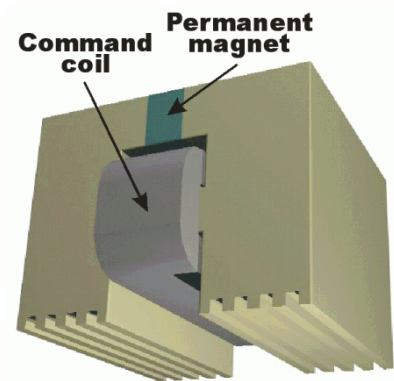


Fig. 2. The mover module

visualisations) and of SIMULINK (simple modular model building, easy to use graphical interface, etc.) are fully exploited [3, 4].

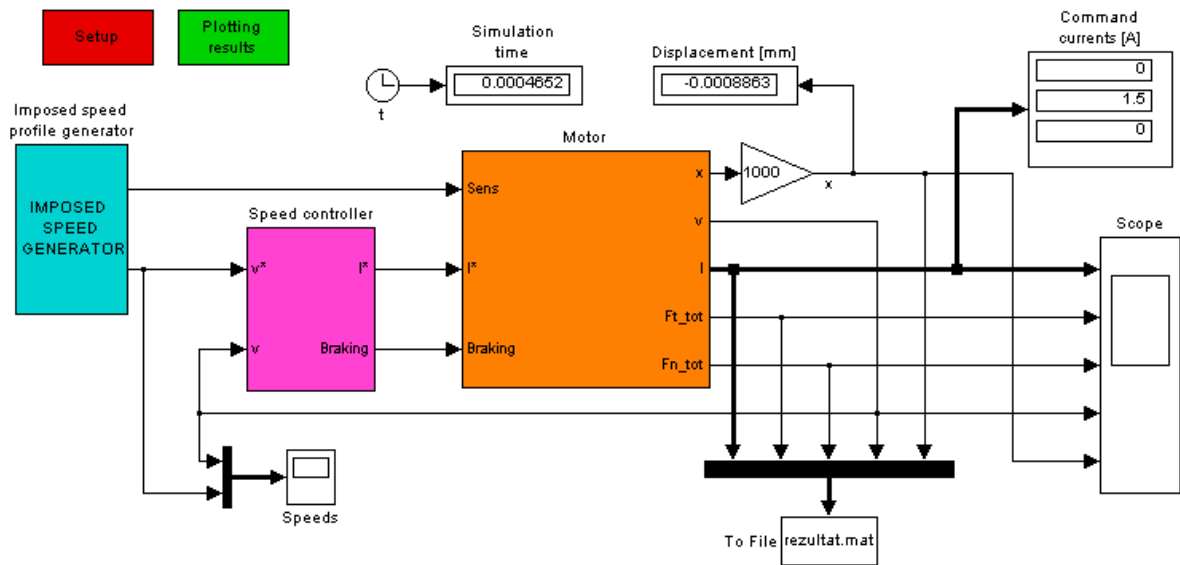


Fig. 3. The main window of the simulation program

The motor's model subsystem is given in Fig. 4. This is also built up modularly: a subsystem is generating the three imposed command currents. In this subsystem are included three S-Function type blocks, obtained by the SIM2SIM linkage with SIMPLORER. These blocks are modelling the power converters feeding the command coils of the linear motor.

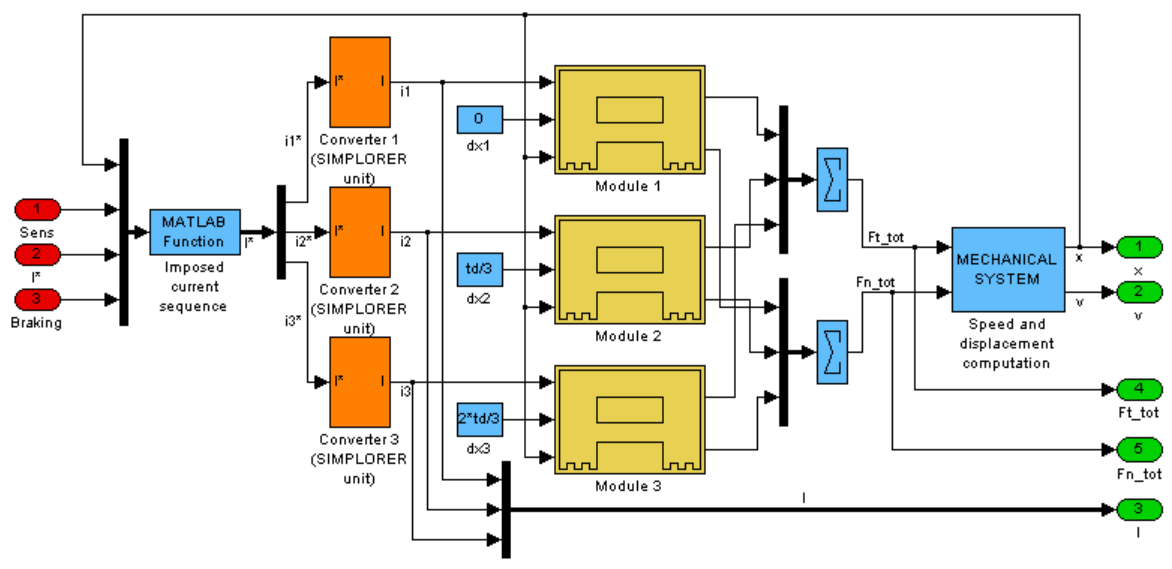


Fig. 4. The **Motor** subsystem of the model

The models of the three modules of the motor were also grouped in a separate block (called **Module 1**, etc.) and are shown in Fig. 5.

The values of the forces for certain currents and displacements are interpolated from two look-up tables (**Tangential Force Determination** and **Normal Force Determination**), containing the static characteristics obtained via the magnetic field analysis performed by the FEM (Finite Element Method) based MagNet program.

The above-presented model can be used for simulating any dynamic regime of the motor. All the motor characteristics can be obtained and plotted in order to make easy its study.

As it was stated out previously, the simulation program of the motor in discussion is a compound of three coupled units; each implemented in different analysis and simulation platforms.

First the unit based on the magnetic field analysis will be presented. Upon the field analysis, made in MagNet 6.0 formerly the simulations, the static characteristics of the motor are computed: the total tangential and normal forces of the motor for different command currents and mover positions [5]. The results are stored in SIMULINK look-up tables. The FEM analysis is the most precise method for determining these characteristics. It is time consuming, but these computations must be done only once for a given motor. The use of the static characteristics of the forces instead of their in-line computation shortens considerably the simulation times.

In order to determine the motor's static characteristics several computations were made. Different control currents (in the range of 0÷2 A) and distinct relative displacements of the mover with a step of 0.1 mm were considered. From the numerous results obtained only two flux plots are presented here, in Fig. 6. (the flux lines for the passive module, having un-energised command coil, and for the active module with energised command coil).

Upon the computed forces the static characteristics of the motor, shown in Fig 7, are determined: the total tangential and normal forces for different command currents versus displacement.

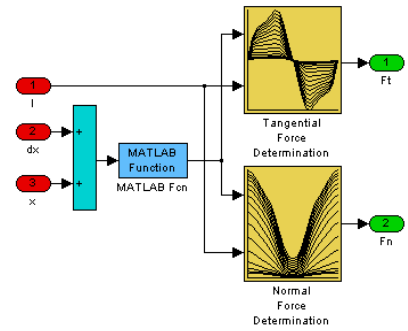
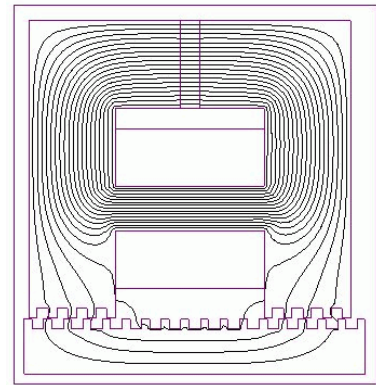
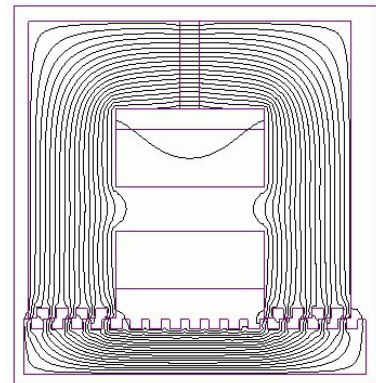


Fig. 5. A mover's model



a) passive module



b) active module

Fig. 6. Flux plots

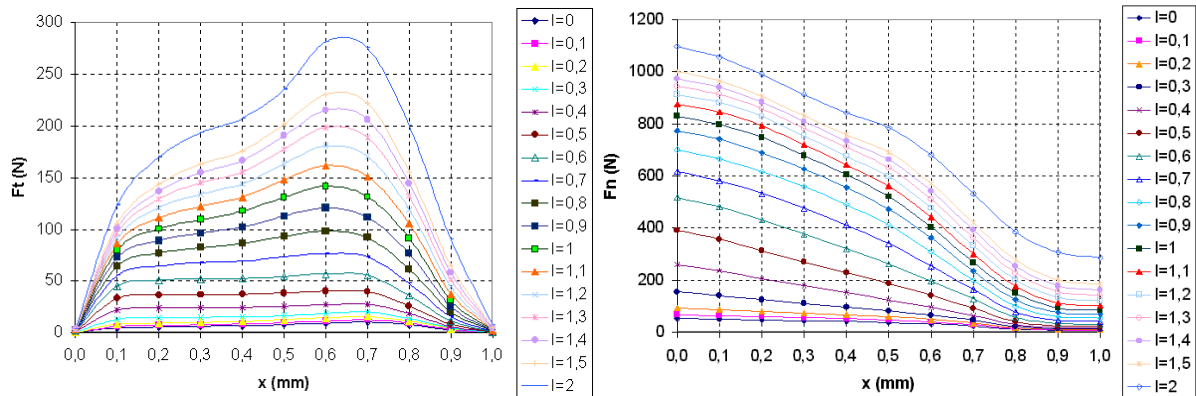


Fig. 7. The static characteristics of the mover's tangential and normal forces

As it can be seen, the drawings on the mask of the look-up table type blocks (Fig. 5) are just the static characteristics shown in Fig. 7.

The power converter feeding the command coils of the motor was modelled in SIMPLORER. This software package is frequently used for simulating comprehensive electric circuit components. SIMPLORER is very user-friendly, due to its graphical interfaces making even complex models easy to define [6].

The power converter unit is composed of three independently working one-phase inverters, built up using dynamic IGBTs. The SIMPLORER model of the single phase H-bridge inverter is shown in Fig. 8.

The so-called SIM2SIM link's interface coupling SIMPLORER and SIMULINK allows the exchange of any variable between a SIMPLORER and a SIMULINK model. The parameter exchanges are clearly arranged, so the different system quantities can be linked easily and quickly. During the simulation an automatic step width control in SIMPLORER and MATLAB/SIMULINK takes place.

The coupling element in SIMULINK is an S-Function-type block. After a multi-step setting process the link between the two different simulation platform can be easily established.

The described program uses the almost best simulation platform for each kind of task [7]. This way the accuracy of the entire simulation is high, and the simulation times are radically reduced. Using this program diverse dynamic regime of the motor can be easily studied. It can be useful during design stage, or for testing different motor variants. It is also advantageous in testing without prototyping of different control strategies of the motor.

RESULTS AND DISCUSSIONS

Numerous dynamic regimes were studied using this model of the three-phase modular hybrid linear stepper motor. Here only the results obtained for a short displacement at controlled speed are given. A typical trapezoidal speed profile was imposed. The maximum speed of the motor was set at 0.5 m/s and the motor will run at this speed 0.09 s. The acceleration, respectively deceleration times were fixed to be 0.03 s.

The sample three-phase motor's rated command current, respectively tangential force is 1 A and 135 N. Its step size is 0.66 mm.

The main results of the simulation are given in Fig. 9. The command currents, the total tangential and normal forces, the speed and the displacement are plotted versus time.

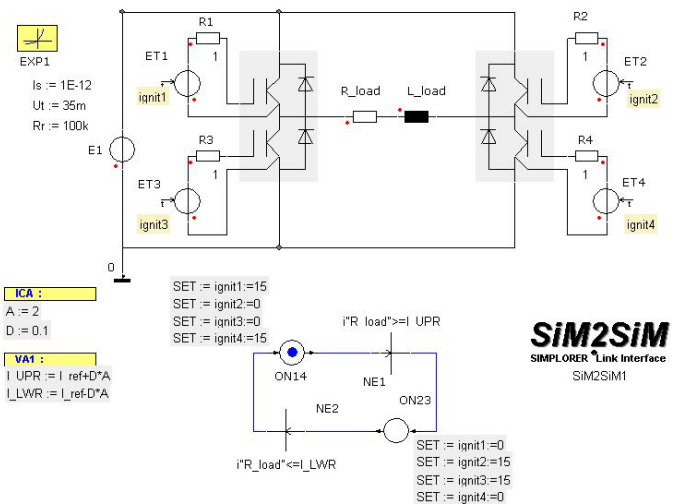


Fig. 8. The SIMPLORER model of the converter

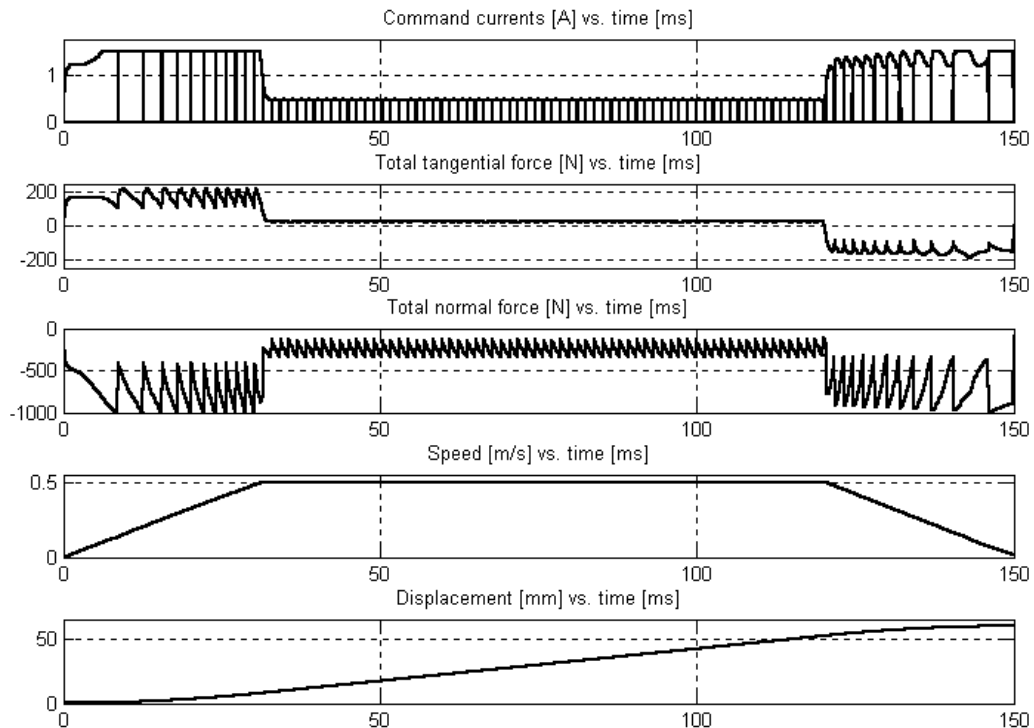


Fig. 9. Results of simulation

As it can be clearly seen in Fig. 9, the imposed speed profile was precisely followed. High tangential forces were needed for accelerating the mover. Due to the high force required for this stage of motion, the command currents also have significant values. After the mover was accelerated, its imposed constant speed may be maintained by low tangential force.

All the obtained results for diverse regimes are in good accordance with the theoretical expectations and also with the results of analytical computations.

The basic idea of coupling in such a manner the different simulation platforms could be successfully applied to any other electric motor.

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