# ON THE USEFULNESS OF COUPLING DIFFERENT SIMULATION ENVIRONMENTS

*Loránd SZABÓ – Jenő Barna DOBAI*
*Technical University of Cluj (Romania)*
*3400 Cluj, P.O. Box 358, Romania*
*e-mail: Lorand.Szabo@mae.utcluj.ro*

**Abstract:** The best way to simulate a complex electromechanical system is by coupling several software platforms, which simulate different subsystems of it. The used simulation programs can be selected as to be among the bests in the given field. In this paper a coupled simulation program of the modular hybrid linear stepper motor will be presented. Three software platforms were used to build up the coupled program: Matlab/SIMULINK, MagNet and SIMPLORER. The usefulness of such coupled programs is discussed, too.

## 1. INTRODUCTION

It is well recognised that computer-assisted simulation is indispensable for understanding dynamics of existing systems, as well as for designing new ones. To exploit the advantages of simulation to their full extent, there are needed simulation software tools and the underlying methodologies applicable across [1]:

- Different engineering disciplines. For example a complex electromechanical system has a multidisciplinary nature because they usually utilise phenomena from several energy domains (mechanical, electrical, magnetic, thermal, etc.) simultaneously.
- Different levels of abstraction. The control system design requires high-abstraction models concerned only about the input-state-output transformations of the system signals (continuous or discrete in time and/or in level). Other, less abstract, models are necessary to characterise energetic interactions between system components for example for virtual prototyping.
- Different levels of idealisation. In some situation a linear lumped-parameter model is fully sufficient for a certain system. In other cases a nonlinear model based on the finite-element-method might be necessary for the same subsystems.
- Different ways of model description. In some cases a description in a textual or graphical form is satisfactory, in others only a description of the external behaviour of the subsystem is satisfactory.
- Different modes of simulation and analysis may be required (numerical or symbolic, time- or frequency-domain, steady-state or transient mode, etc.)
- Geographical distances, to support collaboration of remote teams involved in a common project.

Electromechanical systems are very heterogeneous. Simulating their dynamic behaviour with a single simulation program requires a considerable modelling effort.

Many of the commercial available simulation platforms are focused mostly on a single traditional engineering discipline (control, mechanical engineering, power electronics, etc.). Therefore, to provide the multidisciplinary simulation environment vital for contemporary engineering, unified approaches to system simulation, or interfaces integrating heterogeneous software tools, must be developed [1].

On the other hand from the engineer's point of view it is much more convenient to model directly the different subsystems in their original physical domain or on the most appropriate level of abstraction. Therefore it is inherent to couple different simulation platforms, each used to simulate different tasks (related to the electromechanical system's units) [2]. This is a huge challenge for engineers working in this field.

By coupling multiple simulation platforms is possible to simulate any multi-physics systems, hybrid (continuous + discrete) systems and also lumped-distributed systems. Sometimes, the coupling of different software tools seems to be the "ultima ratio" in simulating multi-domain problem [2].

## 2. THE MODULAR HYBRID LINEAR STEPPER MOTOR

The modular hybrid linear stepper motor was previously presented in several papers [3]. A three-phase variant of this motor is given in Fig. 1.

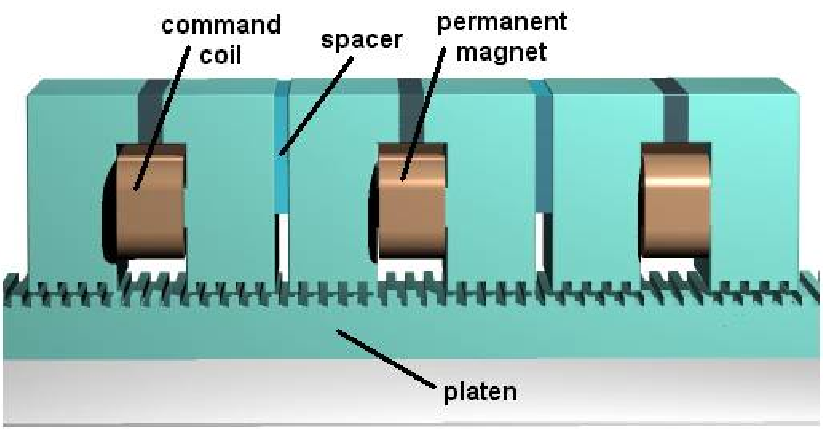



**Fig. 1.** The three-phase modular hybrid linear stepper motor

It is a direct-driven linear motor, which eliminates gearboxes, ballscrews, belts, couplings, or other rotary-to-linear motion converters between motor and load offering superior speed, acceleration, load-positioning accuracy, and rapid stroke cycling, compared to systems based on rotary motors [4].

The mover of the motor is a single stack composed of three modules like that given in Fig. 2. Each module has a permanent magnet, two salient teethed 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.

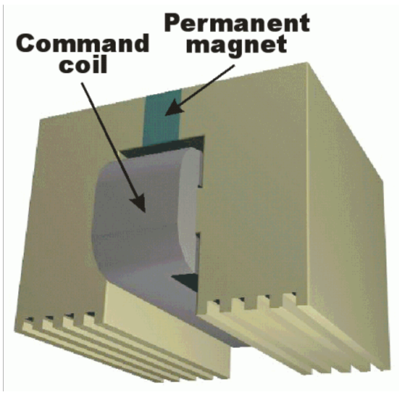



**Fig. 2.** The mover module

The modular linear motor eliminates several disadvantages of the "classical" hybrid linear stepper motors [3]. Due to these benefits it is one of the best choices for industrial applications where fast and accurate linear motions under heavy loads are required.

## 3. THE SIMULATION PROGRAM OF THE MOTOR

The simulation program of the motor in discussion is a compound of three coupled units; each implemented in different analysis and simulation platforms. Its block diagram is given in Fig. 3.

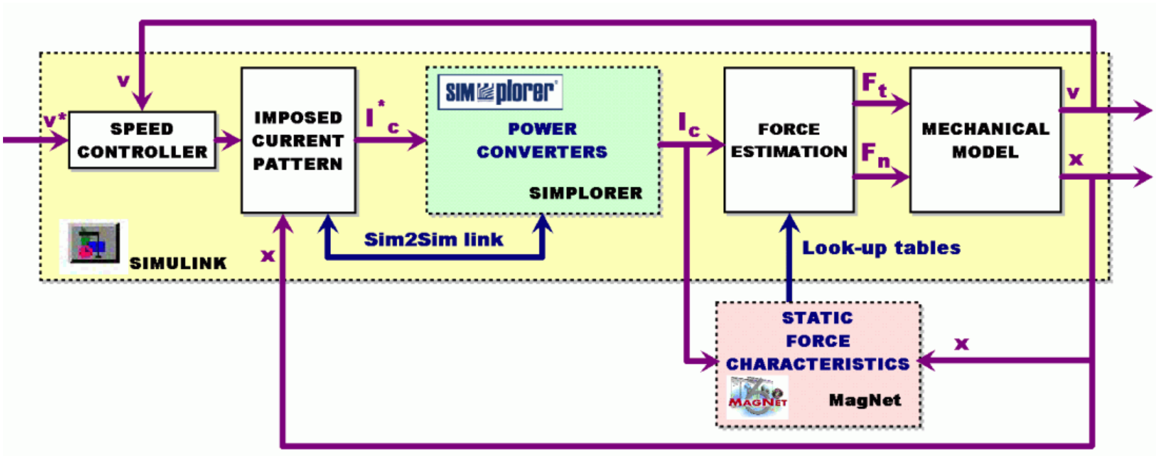



**Fig. 3.** The block diagram of the coupled simulation program

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 dynamic simulation of electrical machines.

The primary window of the simulation program is given in Fig. 4.

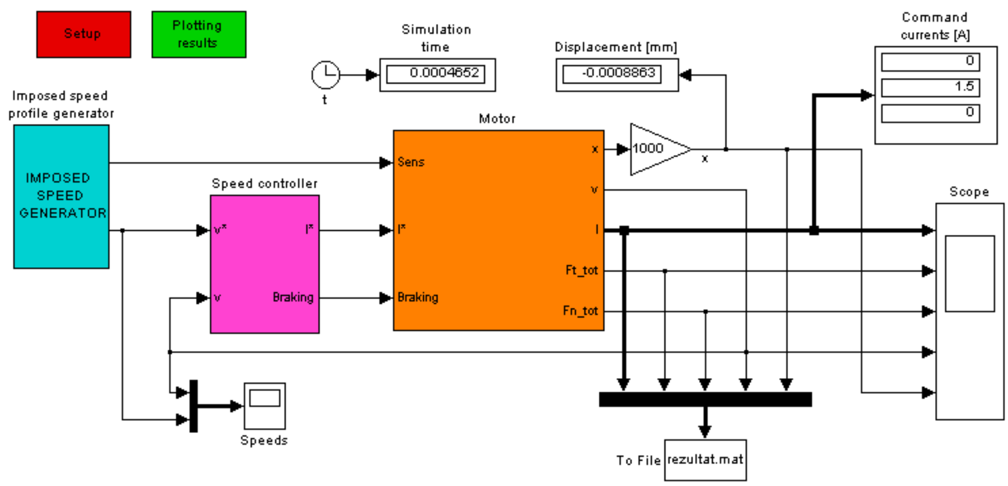



**Fig. 4.** The main window of the simulation program

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 visualisations, etc.)

and of SIMULINK (simple modular model building, easy to use graphical interface, etc.) are fully exploited [5, 6].

The motor's model subsystem is given in Fig. 5. This is also built up modularly: a subsystem is generating the three imposed command currents. In this subsystem is included an S-Function type block, obtained by the SIM2SIM linkage with SIMPLORER. This block is modelling the three-phase power converter feeding the command coils of the linear motor.

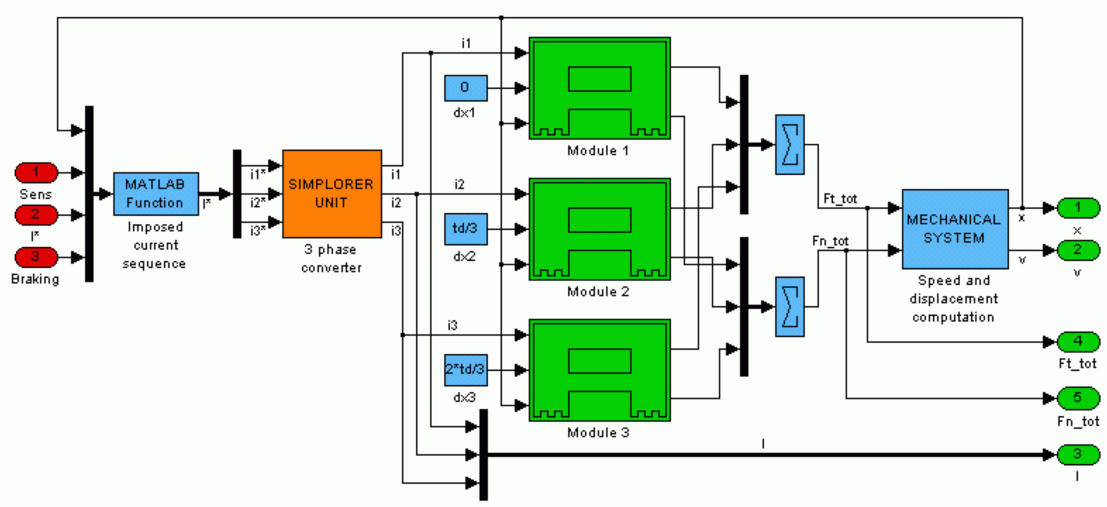



**Fig. 5.** The **Motor** subsystem of the model

The models of the three mover modules of the motor were also grouped in a separate block (called **Module 1**, etc.) and are given in Fig. 6.

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.

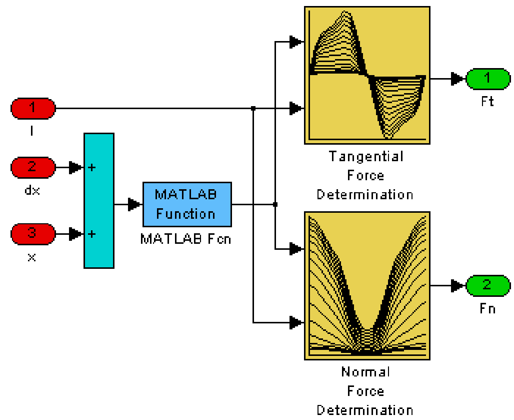
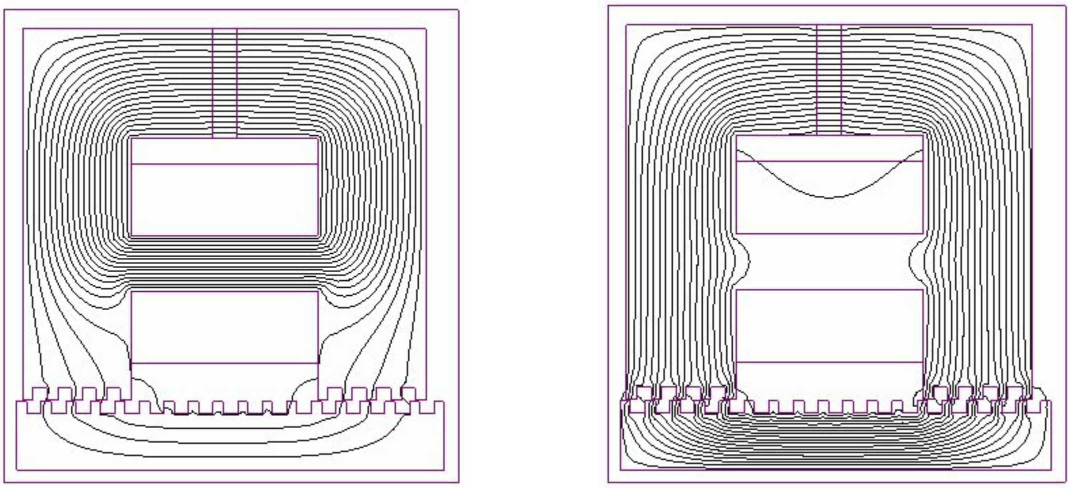



**Fig. 6.** A mover's model

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.

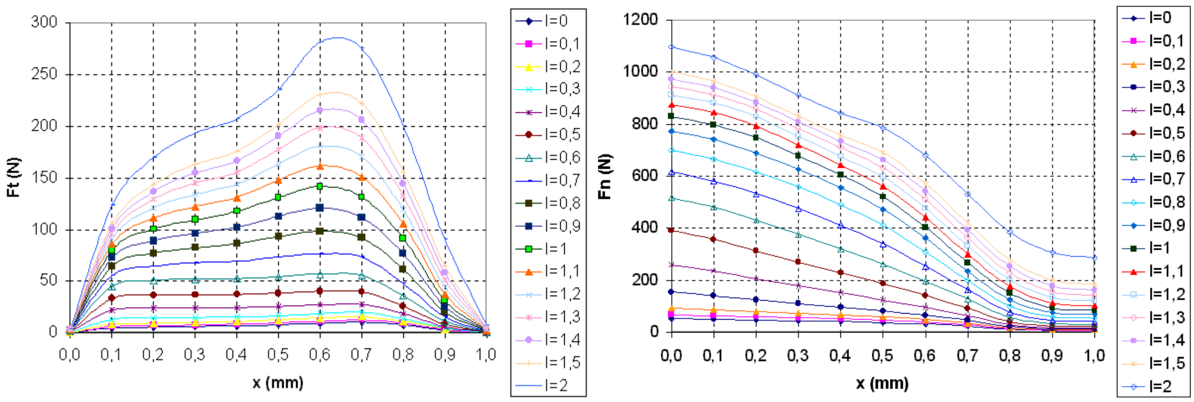
In order to determine the motor's static characteristics several computations were made. Different control currents (in the range of 0÷2 A) and distinct relative displacements of the mover with a step of 0.1 mm were considered. From the numerous results obtained only two flux plots are presented here, in Fig. 7 (the flux lines for the passive module, having un-energised command coil, and for the active module with energised command coil).



a) passive module b) active module

**Fig. 7.** The flux plots

Upon the computed forces the static characteristics of the motor, given in Fig 8, were determined: the total tangential and normal forces for different command currents versus displacement.




a) tangential forces b) normal forces

**Fig. 8.** The static characteristics of the motor

As it can be seen, the drawings on the masks of the look-up table type SIMULINK blocks (Fig. 6) are just the static characteristics shown in Fig. 8.

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 power transistors. The SIMPLORER model of the single phase H-bridge inverter is shown in Fig. 9.

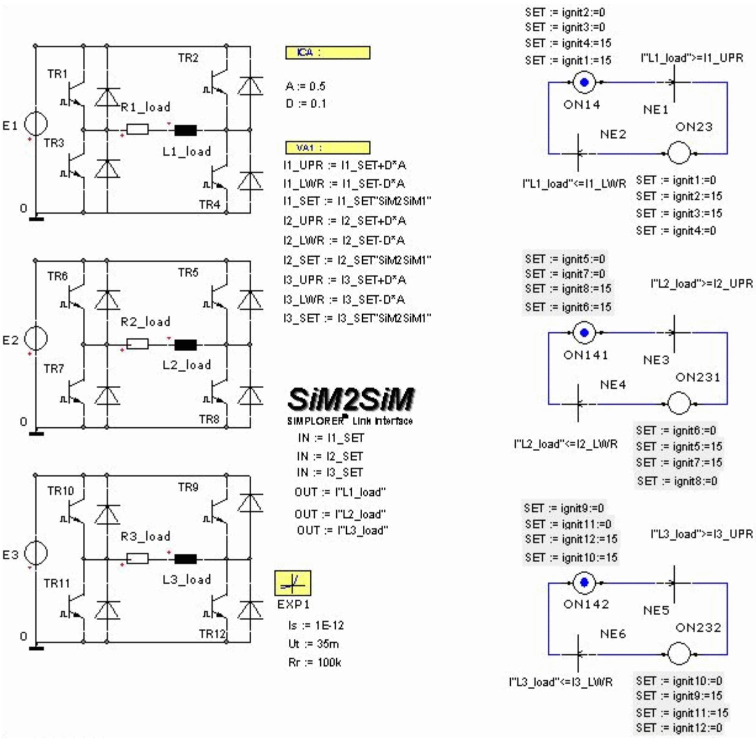



**Fig. 9.** The SIMPLORER model of the converter

The so-called SIM2SIM link's co-simulation interface coupling SIMPLORER and SIMULINK can link blocks in both packages and allows the exchange of any variable between a the two simulation platforms which can operate this way simultaneously. 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 platforms can be easily established.

## 4. RESULTS AND DISCUSSIONS

As it could be seen, the presented simulation program is a compound of three coupled units; each implemented in different analysis and simulation platform. For all the simulation tasks almost the best software environments were used. This way the accuracy of the entire simulation program was increased [7].

The forces for given command current and relative displacement were computed very accurately using the FEM based MagNet package. The SIMPLORER's easy-to-use modelling capabilities were coupled with SIMULINK's powerful system-level simulation capabilities.

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 (10 mm long) displacement at controlled speed are given. A typical trapezoidal speed profile was imposed. The maximum speed of the motor was set at 0.25 m/s and the motor is running at this speed 0.02 s. The acceleration, respectively deceleration times were fixed to be 0.02 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.

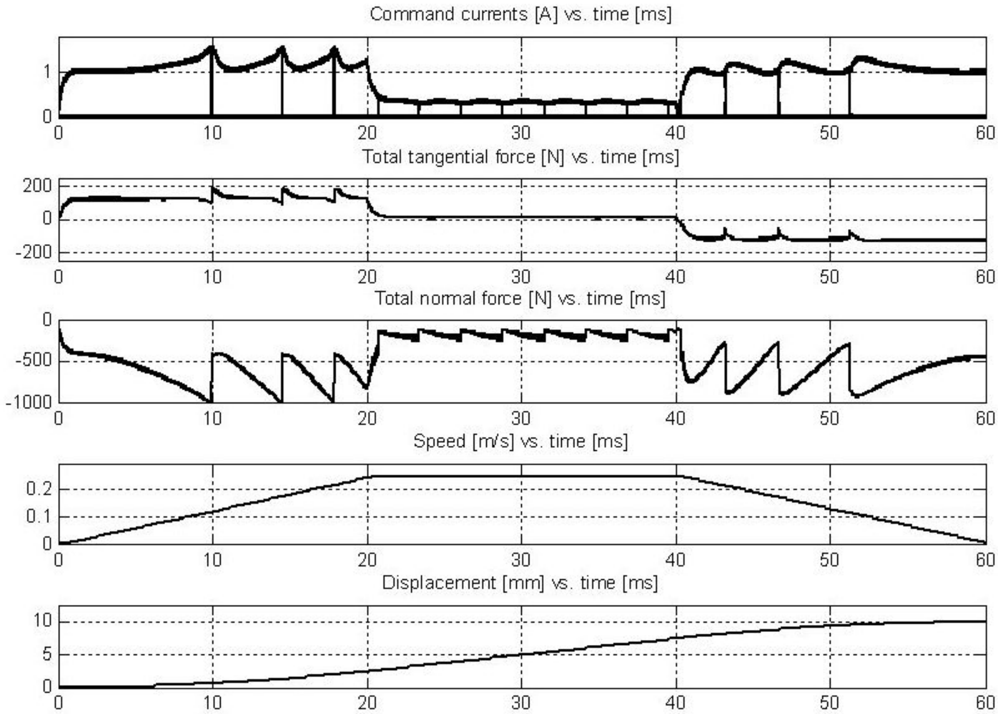
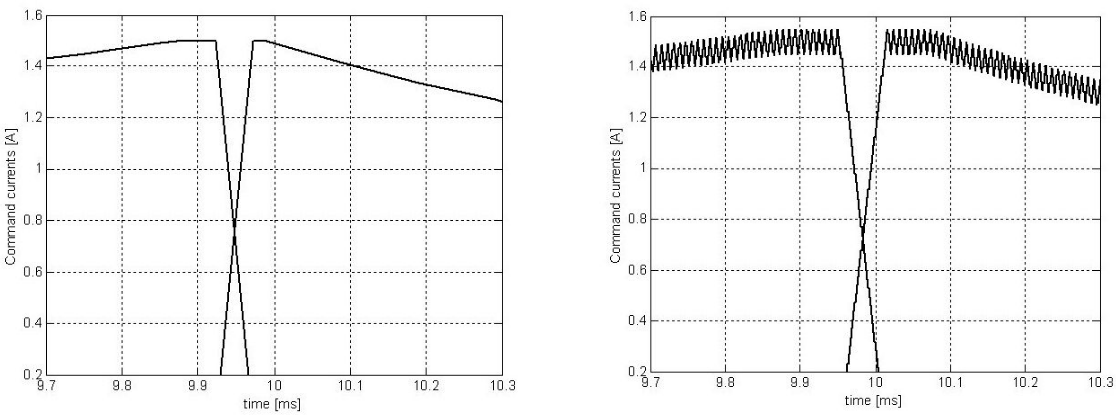



**Fig. 10.** Results of simulation

As it can be clearly seen in Fig. 10, 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, low tangential forces obtained by feeding the motor with reduced command currents may maintain its imposed constant speed.

The use of the look-up tables reduced the computational times, because there was no need to calculate the total normal and tangential forces at each time step. Of course the filling out of these tables required several time-consuming field computations in MagNet, but these field analysis had to be made only once for a given motor.

The simultaneous work of the two platforms (SIMULINK and SIMPLORER) and the exchange of variables at each time step inherently slow down the simulation. The lost time is compensated by the quality of the results. To emphasise this in Fig. 11 the current waveforms during a commutation are presented.




a) simplified converter model b) converter model in SIMPLORER

**Fig. 11.** The command currents waveform during a commutation

In Fig. 11 the command current's waveforms are given for two cases:

a.) when a simplified and idealised converter model implemented in SIMULINK was used

b.) when the converter was modelled in SIMPLORER and this unit was coupled into SIMULINK

It can be seen very clear, that the current waveforms obtained by using the SIMPLORER converter model are much more appropriate of the real currents obtained by PWM techniques.

These results, as all others obtained for diverse dynamic regimes are in good accordance with the theoretical expectations and also with the results of analytical computations.

Direct coupling the SIMULINK platform with a magnetic field analysis program can extend the above presented coupled simulation program's accuracy. At this time both SIMULINK and SIMPLORER can be coupled for example with Cedrat's Flux 2D or Flux 3D program packages. In this case the field analysis is performed at each time step. This is very time consuming, because the time steps must be taken very small (about 50 microseconds) due to the hysteresis current controller's high triggering frequency. It means that for a 60 ms long simulation task (as that presented above) the field analysis should be performed at least 1200 times!

The basic idea of coupling in this manner the different simulation platforms could be successfully applied for simulating all the dynamic regimes of any electric motor driven electromechanical systems.

Finally it can be concluded, that the coupled simulation programs are very useful tools in the design engineers every day practice (during design stage, for testing different motor variants or control strategies without real prototyping) and can be applied in several technical fields.

## 5. REFERENCES


[1] Mann, H., "A Multidisciplinary Web-Based Course on Modeling and Simulation," *Proceedings of the $E=T_eM^2$ Tomorrow's Education in Electrical Technologies*, Liége, pp. 95-104, 2001.

[2] Schwarz, P., Clauss, C., and Haufe, J., "Experiences with coupled simulation of mechatronic and electronic systems," *GAMM Jahrestagung*, vol. MS 9, pp. 199-200. 2001.

[3] Szabó, L., Viorel, I.A., Chişu, Ioana and Kovács, Z., "A Novel Double Salient Permanent Magnet Linear Motor," *Proceedings of the International Conference on Power Electronics, Drives and Motion (PCIM)*, Nürnberg, vol. Intelligent Motion, pp. 285-290, June 1999.

[4] Bartos, F.J., "Direct-Drive Linear Motion Lives!" *Control Engineering*, pp.16-19, April 2003.

[5] ***: *Using Simulink Version 4*. Natick: The MathWorks Inc., 2000.

[6] Dabney, J.B. and Harman, T.L.: *Mastering SIMULINK 2*. MATLAB Curriculum Series. Upper Saddle River: Prentice Hall, 1998.

[7] ***: *MagNet Version 6.6.1 Tutorials*, Montreal: Infolytica Corporation, 2000.

[8] ***: *Simulation System SIMPLORER 4.2. User Manual*. English Edition. Pittsburgh: Ansoft Corporation, 2000.

[9] Szabó, L., Viorel, I.A. and Dobai, J.B., "Multi-Level Modelling of a Modular Double Salient Linear Motor," *Proceedings of the 4th International Symposium on Mathematical Modelling (MATHMOD)*, Viena, Austria, pp. 739-745, February 2003.