A&QT-R 2002 (THETA 13)
2002 IEEE-TTTC International Conference on Automation, Quality and Testing, Robotics
May 23 – 25, 2002, Cluj-Napoca, Romania

COMBINED FEM AND SIMULINK MODEL OF A MODULAR SURFACE MOTOR

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Abstract: Surface (planar) motors are capable of fast and accurate two translation axes motions and they are required in several industrial and laboratory applications. They offer certain advantages over rotational motor driven XY stages due to the lack of rotary-to-linear conversion mechanisms. One of the best choices is the use of the novel, high force, modular surface motors. In this paper a high performance simulation program is presented for the transient analysis of this modular surface motor. It is based on the circuit-field mathematical model of the motor using predefined static characteristics computed via numerical field computation performed using the finite element method. The simulation results obtained for a simple positioning task of the motor emphasis the usefulness of the presented program.

Key words: surface motor, mathematical model, dynamic simulation, finite element method, SIMULINK.

1. INTRODUCTION

Surface motors provide simultaneous orthogonal XY movement in the plane. There are direct driven motors, the load can be put or fixed directly on the mover. Hence they have a lot of benefits, as simplicity, efficiency and positioning accuracy, due to the lack of rotary-to-linear conversion mechanisms, mechanically complex assemblies that require regular maintenance and develop inaccuracies over time [1].

One of the first planar motors the so-called Sawyer motor has typically two linear stepping motors combined into a single housing [2]. The forcer of such a planar motor can move anywhere on the stationary platen surface. It is capable of high position resolution, rapid acceleration and high-speed moves with low mass payloads.

In this paper a new surface motor having high force mover modules is presented. Its advantages are highlighted by means of dynamic simulation. The transient behaviour of the motor is performed by o model set up in the MATLAB/SIMULINK environment. In the applied mathematical model of the motor the field and force computations are substituted with information extracted from a three-dimensional look-up table. It contains information on the correlation between the tangential force developed respectively the command current and relative displacement of a mover, obtained from the FEM based numerical field analysis of the modular surface motor.

All the results obtained prove the ability of the simulated high-efficiency three-phase modular surface motor and the usefulness of the proposed simulation program.

2. THE MODULAR SURFACE MOTOR

The modular surface motor in study (shown in Figure 1) is relatively simple. It consists of two main parts: the platen and the mover (forcer).

The passive platen of steel has a two-dimensional array of square teeth obtained by precise chemical machining. Its surface is planarized using epoxy. It can have any sizes in order to ensure great travel area. The forcer (mover), the active part of the motor, is built up of high efficiency modules (see Figure 2), just like the double salient permanent magnet linear motors, presented in detail in [3, 4].

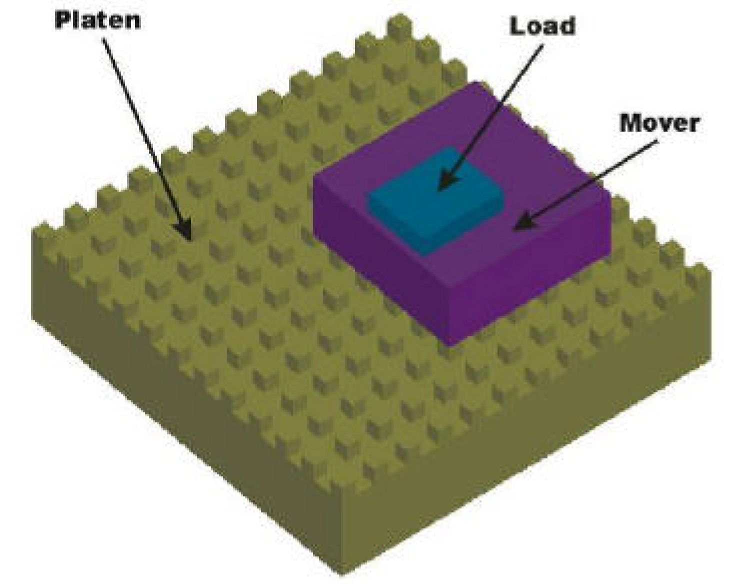

Figure 1. The modular surface motor

Each module has a rare earth permanent magnet, two salient teethed poles (having teeth of width and pitch just like those on the platen) and a command coil. The magnetic flux generated by the permanent magnet can be directed by the command coil to pass through the air-gap and to produce significant forces. Otherwise, when the command coil is not energised, the permanent magnet's flux pass through the core branch in parallel with the permanent magnet, due to its less magnetic resistance than that of the air-gap. In this case there is no significant force produced.

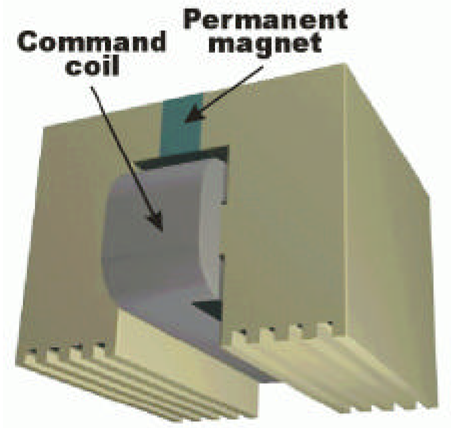

Figure 2. The mover module

Basically the mover is composed of two double salient permanent magnet linear motors, each ensuring the movement in one of the XY directions. For easy control purposes a three-phase motor type was selected. This requires minimally 6 modules, 3 for each direction (see Figure 3). Three of the

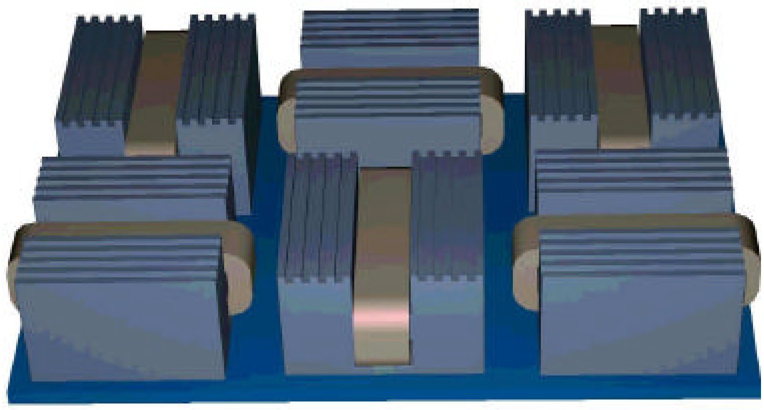
Figure 3. The arrangement of the modules in a three phase surface motor

modules are mounted at 90° to the others in a common housing. One set of coils drives the forcer in the *x* direction and the other in the y direction.

In order to reduce the skew of the mover due to undesired rotational moments a symmetrical structure must be chosen. The simulated motor has totally 36 modules arranged perfectly symmetrical in the mover unit (see Figure 4.). Every phase of the two motor parts (x_1, x_2 and x_3, respectively y_1, y_2 and y_3) is compound of six modules coupled in parallel to the power supply. The mover unit built up in this manner can develop high (several hundreds of N) force on both directions.

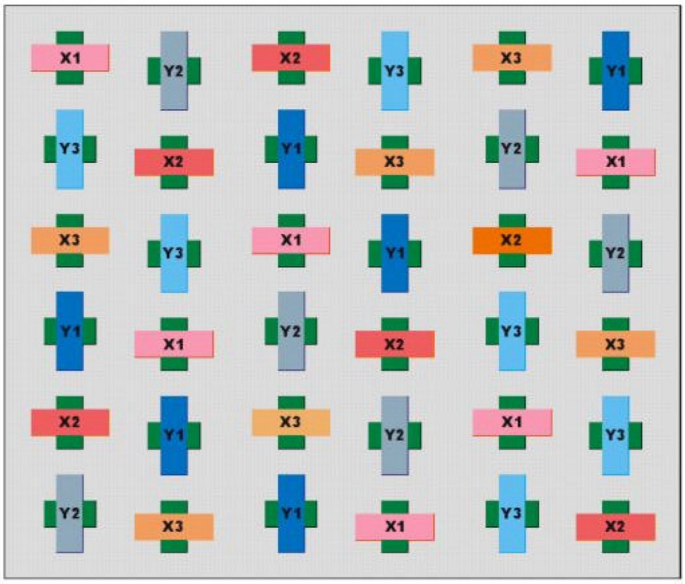

Figure 4. The 36 modules in the mover of the motor

Compressed air flows through the mover, creating a high stiffness air bearing. Thus a uniform, narrow air-gap can be maintained between the platen and the mover in the presence of great attraction forces. Due to the air bearing there are no moving parts and no wear, resulting in greater long-term system accuracy and minimal maintenance.

The presented modular surface motor, in a same manner as the other planar motors can be used in numerous industrial and laboratory applications (for example in electronic or pharmaceutical industry).

3. THE FEM ANALYSIS OF MODULAR SURFACE MOTOR

For the numerical field analysis of the modular surface motor in study the two-dimensional finite element method (FEM) was applied. For all the computations the MagNet 6.10 program package of Infolytica Corporation was used [5].

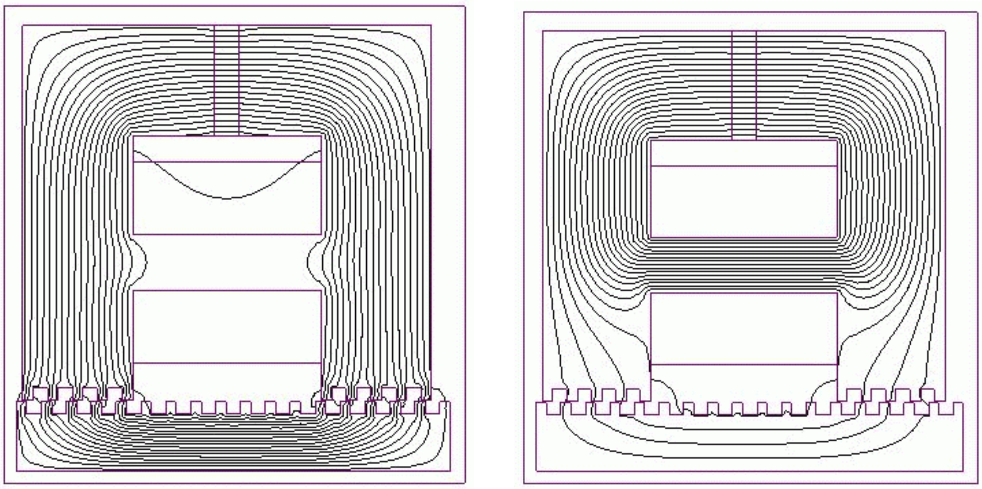

Figure 5. The flux distributions for an active and a passive module

In figure 5 the magnetic flux distributions for an active, respectively a passive module and the platen part above are shown. It is easy to observe the manner, as the magnetic flux generated by the permanent magnet is directed through the air-gap in the first case and concentrated in the core branch under the magnet in the second case.

The tangential force was computed for several different relative positions of the module and for numerous control current values. Using these computations the static force-displacement characteristics of the motor could be plotted [6]. The results were also included in tables to be used in the SIMULINK model of the surface motor.

4. THE SIMULINK MODEL OF THE MODULAR SURFACE MOTOR

The simplest and the fastest way to simulate the transient behaviour of the above presented surface motor is by substituting the field and force computations of the coupled circuit-field model of the motor [7, 8] with information extracted from a 3D look-up table. This table must contain information on the correlation between the tangential force developed, respectively the control current and relative displacement of a mover.

The simulation program was elaborated in MATLAB/SIMULINK environment [9]. The program is modular, it has several sub-system type blocks. This way its high transparency was assured for the all the users. Hence any changes in the program can be made quickly and easily. The main window of the program is shown in Figure 6.

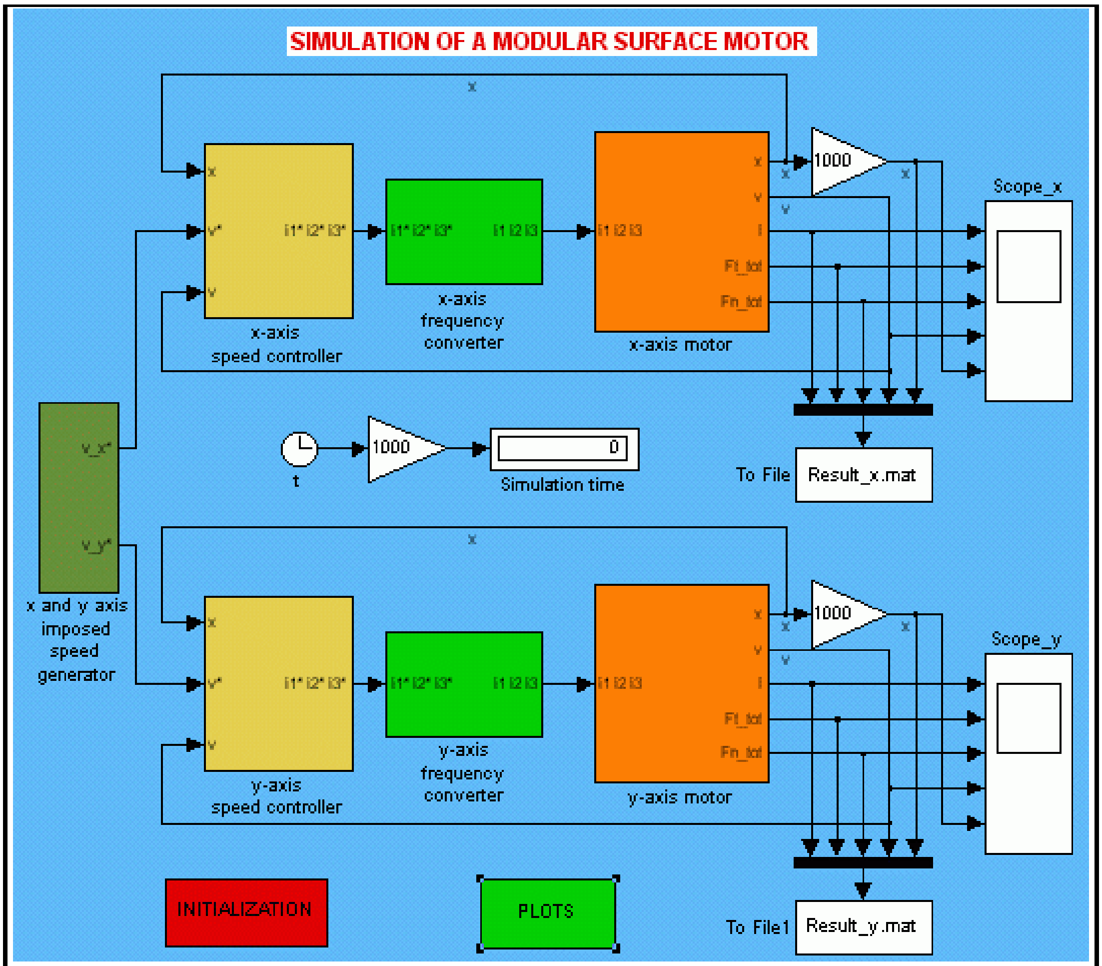

Figure 6. The main window of the simulation program

The simulated task was a typical pick and place type application. Such utilisation of the surface motors can be frequently seen in flexible manufacturing systems. The surface motors carry the product subassemblies from one overhead manufacturing device to another and precisely position the subassembly so that the overhead devices can perform their required actions.

During the simulated task the mover starts without load from its initial position, A, and moves into position B. Here the load is put on the mover and it is displaced in C, where the load is taken down and the motor returns to its initial position (see figure 7). Three trapezoidal speed profiles must be generated for all the sequences of the task for each direction of movement.

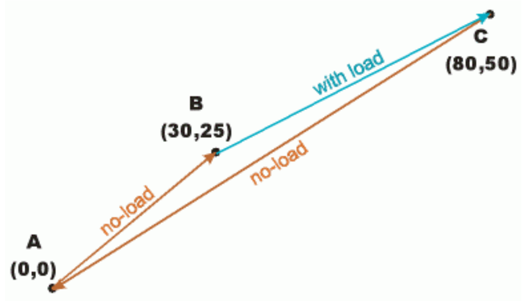

Figure 7. The simulated motion task

The main results of the simulation for the part of the motor that ensures the displacement in *x* direction is shown in figure 8. The command currents, the total tangential and normal forces, the speed and the displacement are plotted versus time.

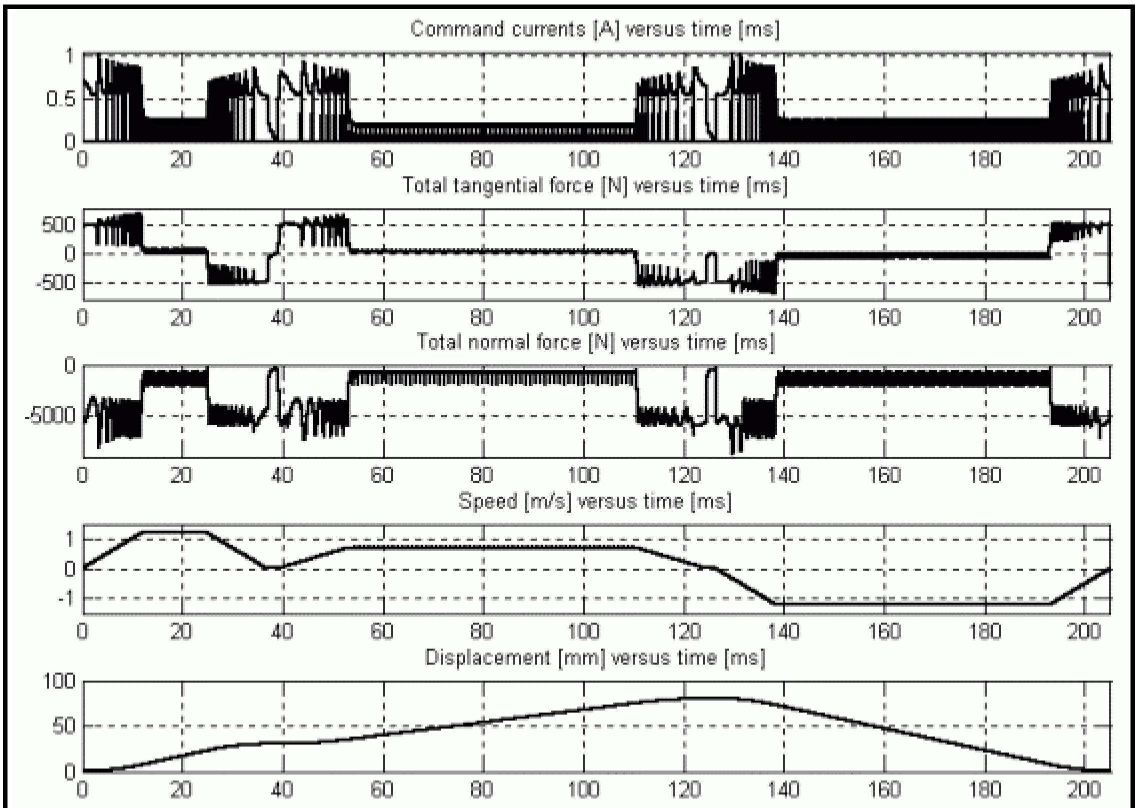

Figure 8. The results of simulation for the *x* motor

As it can be clearly seen in the figure, all the three imposed speed profiles were closely followed up. High tangential forces were needed for accelerating the mover. Due to the high force required the command currents for this stage have also significant values. After the mover was accelerated its imposed constant speed may be maintained by low tangential force.

5. CONCLUSIONS

The modular surface motor presented in this paper can be very useful in several industrial and laboratory applications where precise, high speed and force planar movements are requested. It can be assembled for different peak forces and positioning accuracy in accordance with the user's needs.

The simplest and the fastest way to simulate the transient behaviour of this surface motor is by using the MATLAB/SIMULINK environment, one of the best choices for dynamic simulation of complex systems. In the applied mathematical model of the motor the field and force computations are substituted with information extracted from a 3D look-up table, containing information on the correlation between the tangential force developed respectively the control current and relative displacement of a mover. This information was obtained from the numerical field analysis of the modular surface motor performed using MagNet 6.10 package.

The fast simulation times confirm the usefulness of the precomputed 3D look-up table instead of the time consuming equivalent magnetic circuit or FEM based field computations that must be performed at each time step of the simulation.

Finally it can be concluded that all the simulation results obtained prove the ability of the proposed high-efficiency three-phase modular surface motor.

6. ACKNOWLEDGEMENTS

This research partly was made possible by funding of the Institute of Research Programs of the Sapientia Foundation Cluj (Romania).

The authors would like to thank to professor Ioan-Adrian VIOREL for his useful helps and advises regarding the modular double salient permanent magnet linear motor.

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