SIMULATION MODEL OF THE COUPLE OF LINEAR MOTORS

Jan Knobloch
Doctoral Degree Programme (1), FEEC BUT
E-mail: xknobl00@stud.feec.vutbr.cz

Supervised by: Bohumil Klíma
E-mail: klima@feec.vutbr.cz

ABSTRACT

The article discuss the preparation of linear synchronous motor model, derived from the rotation motor. Motor plate parameters are inputs of the simulation model. Furthermore, attention is focused on the presentation of simulated dynamometer and schemes in MATLAB-SIMULINK environment. Finally, the simulation is executed and the results are presented.

1. INTRODUCTION

Linear motors found frequent application in dynamic applications such as filling machines, CNC machines and various robots. Their advantages are the absence of transmission mechanisms, improved dynamics and precision.

Measurement of parameters of rotating machines is done on a dynamometer. The aim is to simulate the dynamometer for testing of the linear motors in MATLAB-SIMULINK. In this article only the synchronous linear motor with permanent magnets on the secondary part will be considered.

2. SIMULATION MODEL OF SYNCHRONOUS LINEAR MOTOR

Let's introduce the principle of the linear motor and its model. Then we proceed to simulate the couple of linear motors.

2.1. PARAMETERS OF LINEAR MOTORS

The motor plate including the following parameters: F_{peak} and I_{peak} – maximum force and current peak, F_{nc} and I_{nc} – force and current with the nominal cooling, k_E – voltage constant, k_F – force constant, $R_{u\text{-}v}$ and $L_{u\text{-}v}$ – resistance and inductance between the terminals of the motor.

Voltage constant is fraction of the RMS value of induced voltage and speed. Force constant is fraction of the actual force and the actual RMS phase current. Both of these constants are currently the only one electromechanical constant. The relationship between them is $k_F = k_E \cdot \sqrt{3}$. For the modeling purpose we can introduce the equivalent magnetic flux of permanent magnets Φ_m. Valid:

$$\Phi_m = k_F \cdot \frac{d_m}{3 \cdot \sqrt{2} \cdot \pi} \quad (1)$$

Where d_m is twice of the pole pitch $d_m = 2 \cdot \tau_p$. Specific parameters can be found in documentation [3].

2.2. Simulation model of synchronous linear motor

The model of synchronous linear motor with permanent magnets is given in the "rotor" coordinates. It is derived from the model of rotary PMSM motor, which is based on the general theory of electrical machines.

The model is valid only under the (simplistic) terms: the windings is three-phase, symmetrical, connected in star and with not connected central node, magnetising characteristic is linear, loss in the magnetic circuit is zero, resistances and inductances are constant, air gap is constant, magnetic field in the air gap has a sinusoidal distribution and in the longitudinal axis is constant, boundary effects and the influence of the grooves is not considered.

The machine model is described in the d-q coordinate system that rotates with electrical angular velocity $\omega_K = \omega_{el}$. Synchronous linear motor consists of a primary part (equivalent of the stator) and secondary part (equivalent of the rotor). Direction of the "rotor" excitation magnetic flux vector is identical with the axis d. For linkages fluxes ψ, voltages u and currents i, the following equations are given. For linear motor with a smooth secondary part, the inductance in axis d is the same as the q-axis inductance $L_d = L_q = L$, as well as in the equivalent rotary motor.

$$\frac{d\,\psi_d}{dt} = u_d - R \cdot i_d + \omega_{el} \cdot \psi_q \quad (2)$$

$$\frac{d\,\psi_q}{dt} = u_q - R \cdot i_q - \omega_{el} \cdot (\psi_d + \Phi_m) \quad (3)$$

$$i_d = \frac{\psi_d}{L}\ ,\ i_q = \frac{\psi_q}{L} \quad (4)$$

For force is valid:

$$F_i = \frac{3}{2} \cdot \frac{2\pi}{d_m} \cdot i_q \cdot \Phi_m \quad (5)$$

The SIMULINK implementation of equations (2) to (5) is on Fig. 1. More details about the general theory of electrical machines and its control can be found in literary [2].

Although the equations motor are created for rotary motor, for a linear machine are posible use. From the perspective of the terminals linear motor looks like rotary motor. Transfer from linear to rotary motion is then realized by virtual wheel with the circumference d_m, mounted on the shaft of a imaginary rotary motor.

On the motor is used the vector control to maximum force (torque). It means that stator linkage flux vector (q axis) is perpendicular to the rotor flux vector (q axis). The control structure is depicted in Fig. 3. The controller maintains a current (linkage flux) only in the axis q, d-axis current keeps zero. In real situation is necessary to use the coordinate transformation system. For more see [2].

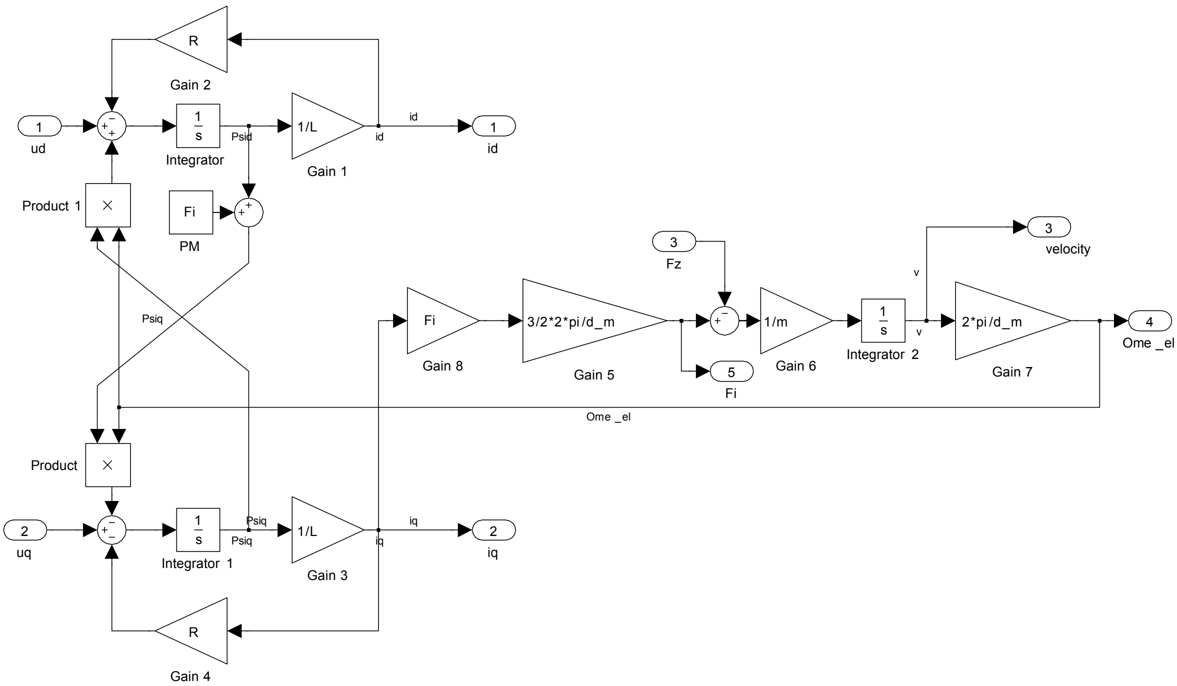

Fig. 1: Model of a synchronous linear motor in MATLAB / SIMULINK

3. SIMULATION OF THE COUPLE OF LINEAR MOTORS

Simulated machinery sketch of couple of linear motors is shown on fig. 2. Directions of speed and forces that correspond with the simulation are determined.

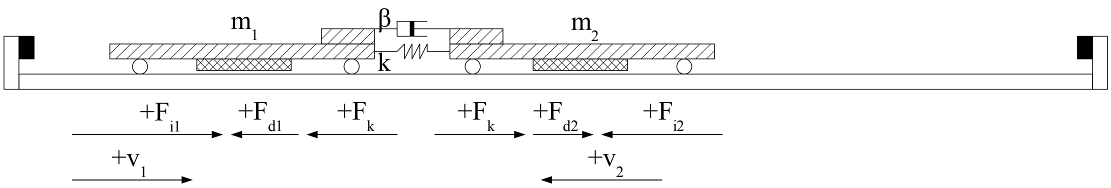

Fig. 2: Sketch of the simulated device

Whole set of the couple of linear motors model is shown on fig. 3. Upper (measured) motor is controlled in position cascade control feedback loop. Lower motor (dynamometer) is controlled by the force regulator with feedback from the force sensor.

The force pulsation due to position-dependent reluctance (cogging) is here modeled externally, outside motor model, as well as friction in bearings. Force sensor is modeled as a spring. Two motors at the ends of force sensor (spring) are mechanical oscillating system. When occur sudden changes of force, then measured force F_k oscillate. At a certain speed may also happen that the frequency of pulsating force (cogging) gets into resonance with the natural frequency of the mechanical resonator. That may cause force sensor overload.

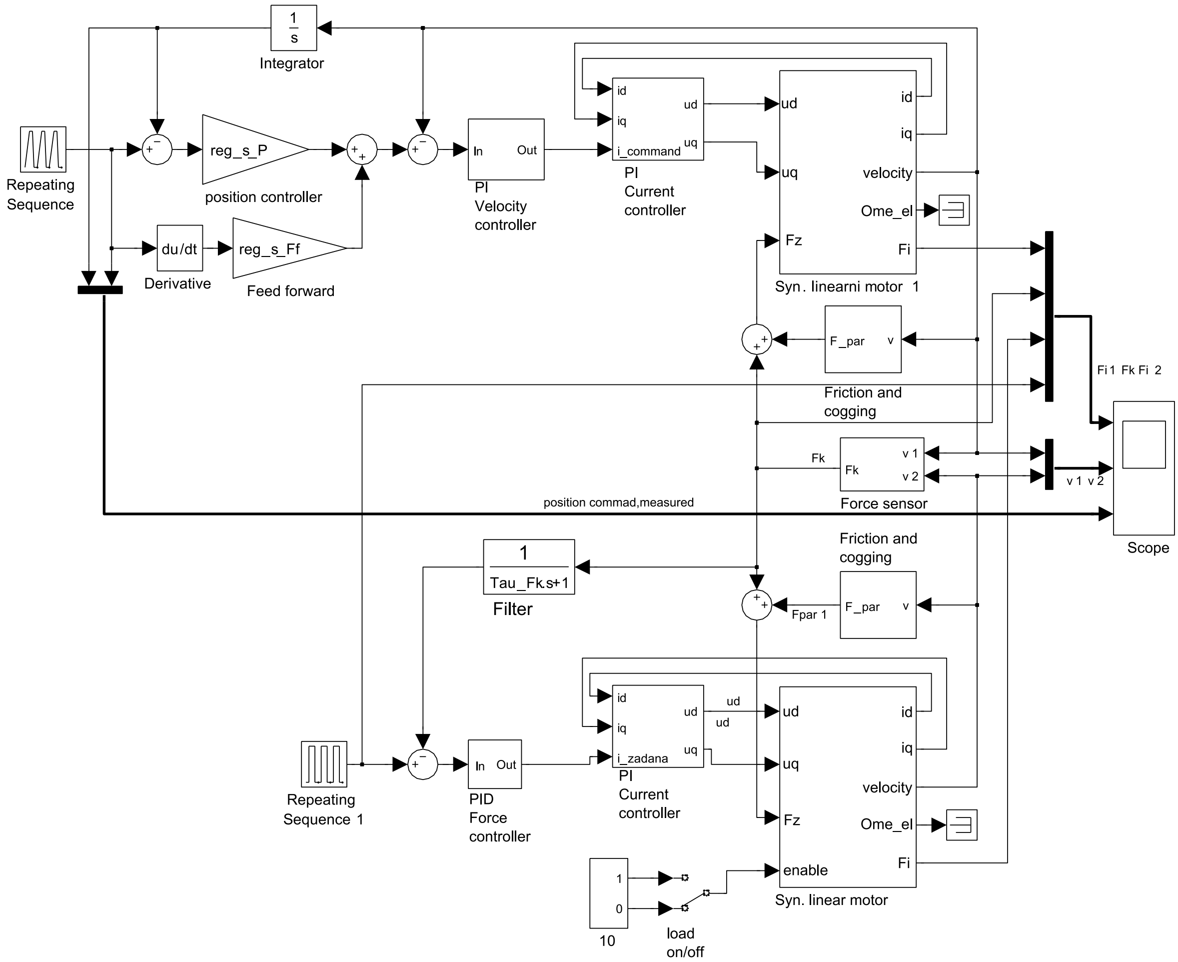

Fig. 3: Schema of the device for measuring linear motors

4. SIMULATION RESULTS

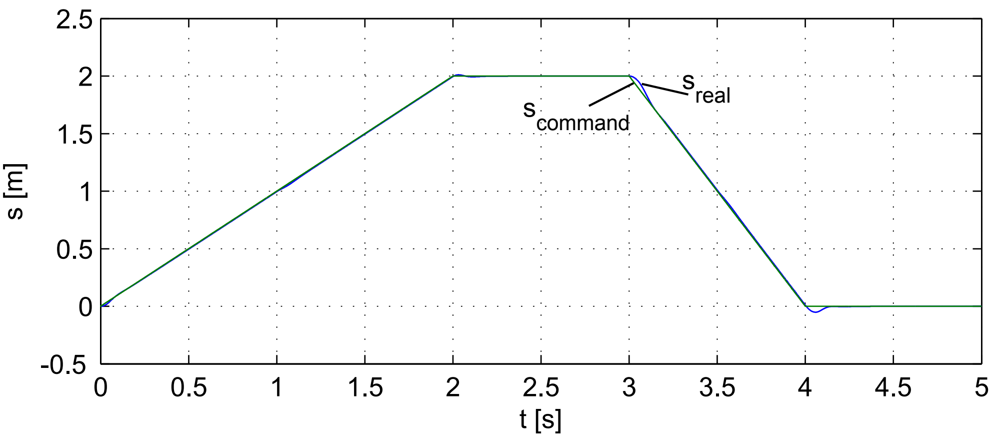

Fig. 4: Results of simulations: demanded and actual position

Figure 4 shows the position depending on time. The symbol $s_{command}$ is the required position and s_{real} the real position. At the time t = 0s, the machinery starts going a constant velocity of $1ms^{-1}$ to reach the position s = 2000mm. At the time t = 2s, the motor stops, so it can at time t = 3s start velocity $2ms^{-1}$ back to the home position. Here the motor stops at the time t = 4s.

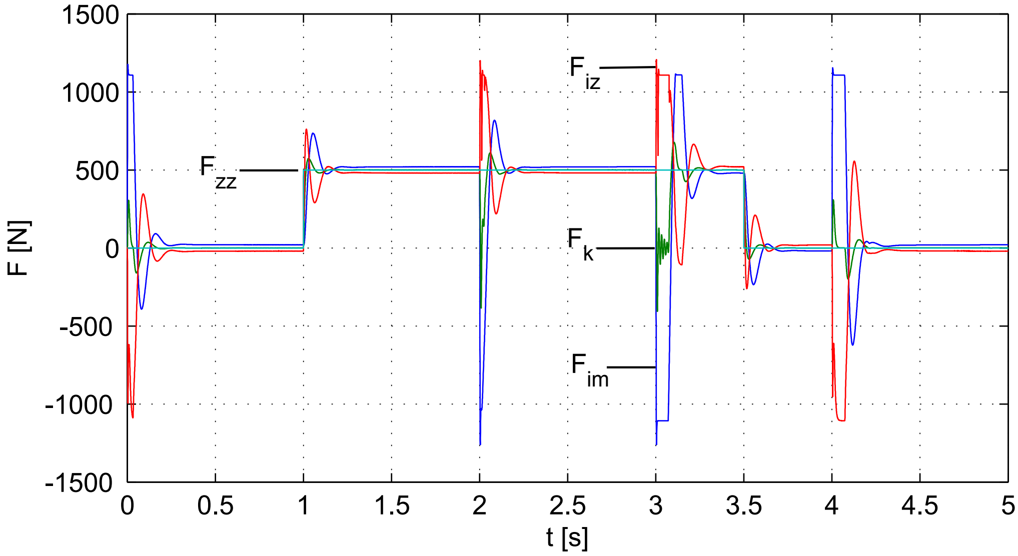

Fig. 5: Results of simulations: force at motor, sensor, load and the required

On Fig. 5 are the waveforms of forces. At time t = 1s the whole machinery runs and there is a jump of force demand F_{zz} = 500N. At the time t = 2s, the motor stops and force is still 500N. To acceleration back at the time t = 3s contributes load motor too. You can see the oscillation of really measured force F_k. At the time t = 3.5s is the requirement of force F_{zz} = 0N. At the time t = 4s machinery stops.

5. CONCLUSION

Model allows to test the operating conditions before using the procedures to real device. This makes it possible to avoid failure or accident. The simulations carried out lesson for building real device. Here should not miss the force sensor with damper.

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