Study on Control System of Permanent Magnet Linear Synchronous Motor

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Abstract – **The study is forced on behaviour of control system of a linear synchronous motor at different loads and different speeds. Modelling and simulation is performed in Simulink environment. The proposed control model can be used as a dynamic study basis for linear synchronous motors with permanent magnets.**

Keywords – **Linear synchronous motor, Dynamic model, System control, Load, Speed.**

I. Introduction

Approximately 50% of the produced energy is used for electric drives of different industrial systems [2]. Exceptional variety in the range of power and control could be recognized among the systems of automatic electric drive.

The automatic control systems for electric drive feature wide range of speed control; excellent control accuracy of the coordinates, speed and security; economy; good communication devices; easy service and maintenance; ecology etc.

In modern productions a number of auxiliary devices are built such as various sensors for speed feedback and position (precisious tacho generators, impulse sensors, code sensors, resolvers, etc.), electromechanical brakes, fan with forced cooling, driving screws, gearboxes etc [3].

These elements can increase additionally the fluctuations in the mechanisms, complicate the design and lead to greater complexity in managing with lower reliability.

Last decade was dedicated to different applications of linear motors. Driving systems for transport and material handling using linear motors now are part of the so-called gearless design.

Difficulties for large-scale production of linear drives are still high costing and difficult in preparing linear motors with an arbitrary profile and length. In addition, the magnets in the linear synchronous motors are made of expensive and rare metal. It is expected that prices of magnets will decline in response to the fast-paced production and development of technologies producing magnets [4]. The price of the linear motor depends on the length of the motor, and it is a 1.5 to 3 times higher than that of traditional rotary motor [7]. Despite these shortcomings, the interest in the deployment of linear drives in the industry is constantly growing. Growth of interest in the usage of linear drives during the period between 1992-2005 can be seen on Fig. 1 [6]. For this period 272 presentations were published at the conference; 51 reports in magazines, which concerned the linear drives; three magazines have each published 2 reports of the conference with control plus linear motor in the title.

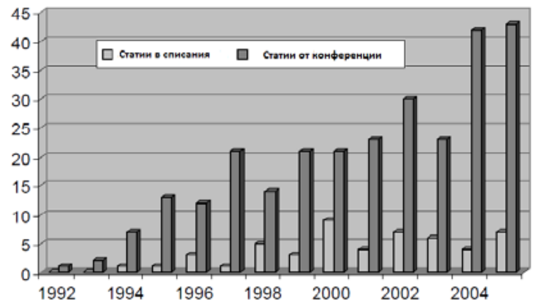

Fig. 1. Number of publications in which appears the name of the linear motor appears and their control according to IEEE Xplore

The main aim of the study is to create a simulation mathematical model in Simulink environment of the system control of linear synchronous motor with permanent magnets.

II. Methods and Means of Research

The method which is applied to consider the dynamics of linear synchronous motor systems is based on principles of vector control. The means of the research is simulation modeling using Simulink system and SimPowerSystem.

III. Mathematical Description of the Dynamic Model of the Linear Synchronous Motor with Permanent Magnets

The angular velocity of the linear synchronous motor with permanent magnets is connected to the linear synchronous speed of the motor by following equation [4], [5]:

$$\omega_e = \frac{\pi v}{\tau}, \quad (1)$$

where v -is a linear speed of movement; τ -poles pitch.

The equation of the electromagnetic balance can be written in the following form:

$$\vec{u} = R\vec{i} + \frac{d\vec{\lambda}}{dt} - \vec{\omega} \times \vec{\lambda}, \quad (2)$$

where $\vec{\omega} \times \vec{\lambda}$ - is the rate of change of voltage in a rotating magnetic field.

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Presenting scalar components of vector (2) on the axes d and q we can obtain voltage equations of linear synchronous motor with permanent magnets as follows:

$$\begin{cases} u_d = R.i_d + L_d \dfrac{di_d}{dt} - \omega_e.L_q.i_q \\ u_q = R.i_q + L_q \dfrac{di_q}{dt} + \omega_e L_d.i_d + \lambda_f.\omega_e \end{cases} , \quad (3)$$

where

u_d, u_q - are d, q axis stator voltage;

id, *iq* - d, q axis stator current;

Ld, *Lq* - d, q-axis armature self-inductance;

R - stator winding resistance;

ω_e - angular velocity;

λ_f - flux linkage of permanent magnet.

The instantaneous electromagnetic power can be expressed by:

$$p_{em} = \frac{3}{2}.\omega_e.\left[\lambda_f + \left(L_d - L_q\right).i_d\right].i_q , \quad (4)$$

where p_{em} - is instantaneous electromagnetic power.

Linear force on the horizontal axis is determined by the formula:

$$F_x = \frac{p_{em}}{v} = \frac{3}{2}.p.\frac{\pi}{\tau}(\lambda_d.i_q - \lambda_q.i_d), \quad (5)$$

where p - is a pole pairs.

Linear force of the system in the present article is carried by the laws of vector control of electric motors. If the motor inductance is small as in the present study, the control of the flux will not give the desired result. A suitable method for control is, if the engine is controlled by the axis q, i.e. constancy of the vector in the inductor current. In this case it is assumed that the current in the axis d equals zero, i.e. $i_d = 0$.

Adopting this type of control, the equation of the electromagnetic force (5) is transformed into the following form:

$$F_x = \frac{p_{em}}{v} = \frac{3}{2}.p.\frac{\pi}{\tau}.\lambda_d.i_q . \quad (6)$$

The angle θ is determined by the formula:

$$\theta = \frac{d\omega}{dt} = \frac{\pi}{\tau}.\frac{dv}{dt} . \quad (7)$$

A. Design of the System in Simulink Environment

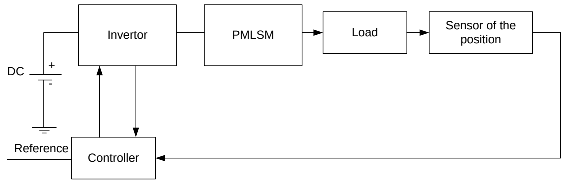

Fig. 2. Schematic control of linear synchronous motor with permanent magnets

The elements of the above shown scheme have the following realization in Simulink environment:

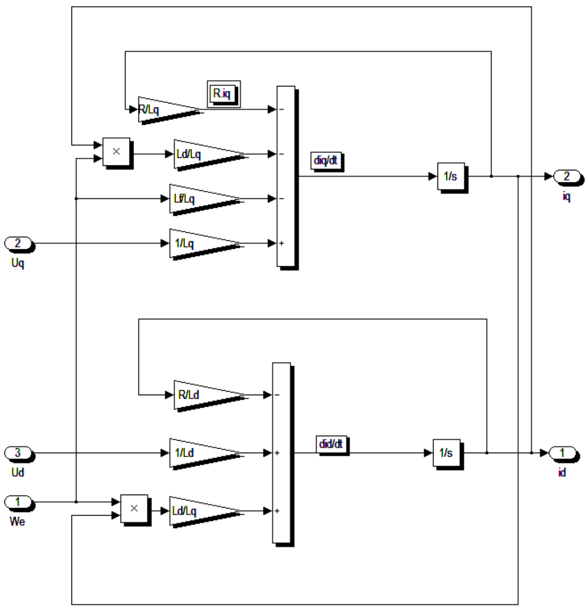

Fig. 3. Realization of voltage equations in Simulink environment

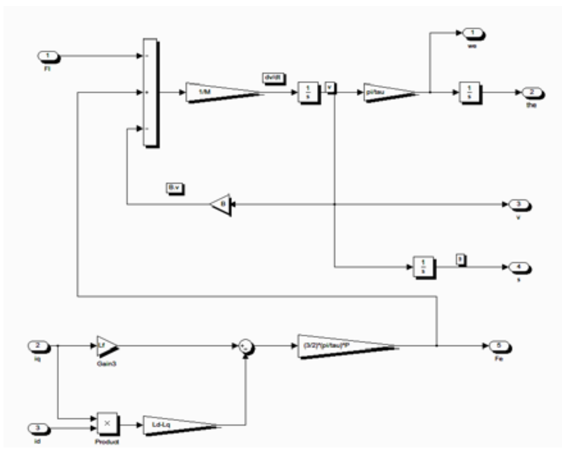

Fig. 4. Realization of the electromechanical part of a linear synchronous motor with permanent magnets in the Simulink environment

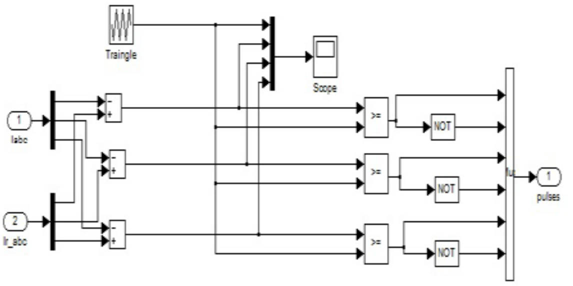

Fig. 5. Realization of the controller in the Simulink environment

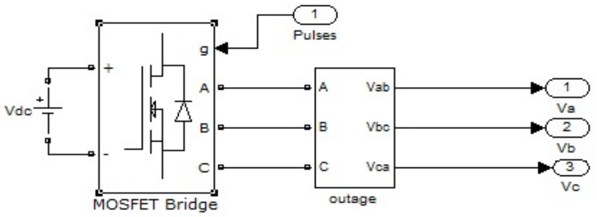

Fig. 6. Realization of the inverter in Simulink environment

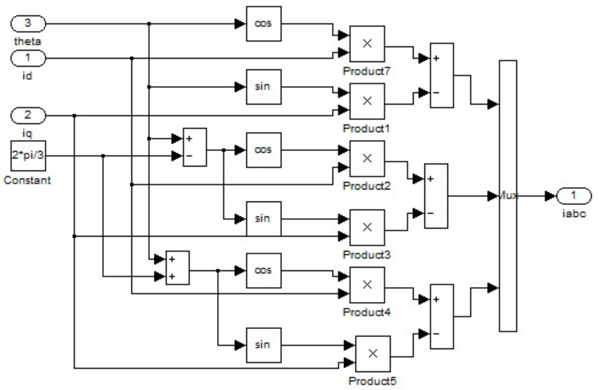

Fig. 7. Realization of modules for conversion of two-phase rotating frame into three-phase rotating frame

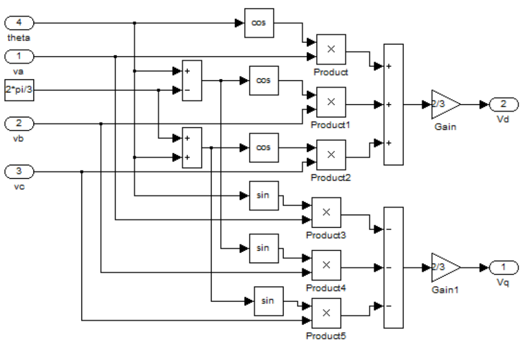

Fig. 8. Realization of the module for converting the three-phase coordinate system into a two-phase coordinate system

IV. Results and Discussion

Tested was performed by permanent magnets linear synchronous motor with the following data: $R = 3{,}2\ \Omega$; $L_d = L_q = 8\,mH$; $\lambda_f = 83Wb$; $\tau = 33mm$; $p = 2$; $B = 0{,}2\ N.s/m$; $M = 10\,kg$. Frequency of the inverter is $6000Hz$.

The study is constructed by two essential cases, namely:
1. Constant speed and variable load,
2. Variable speed and variable load.

The results obtained in the simulation are presented in Figs. 9 and 10.

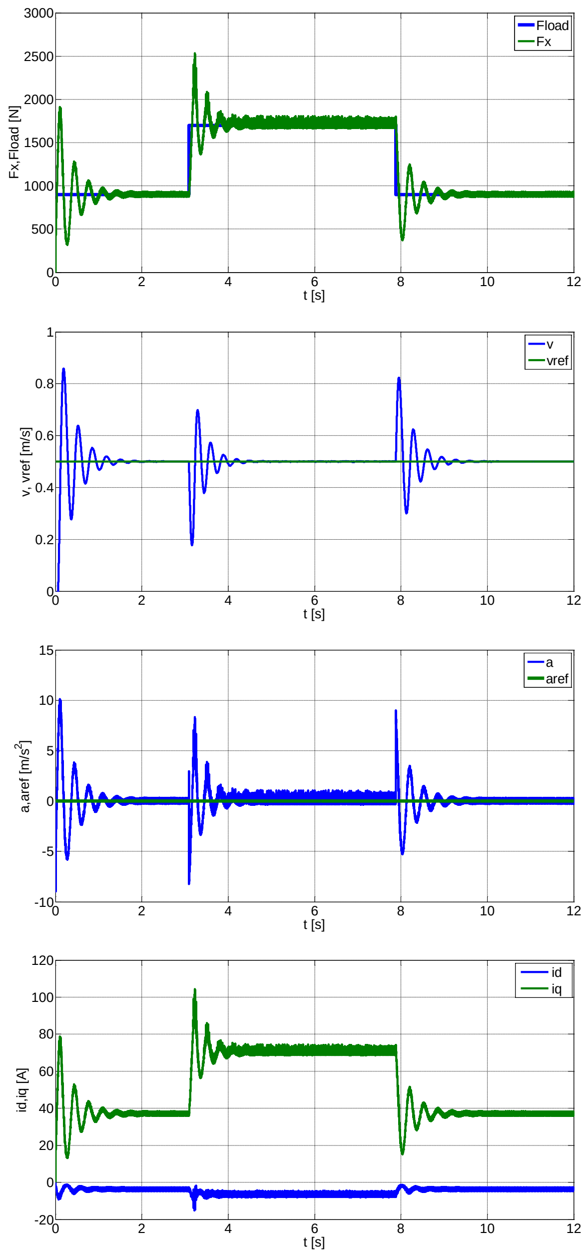

Fig. 9. Testing at a constant speed and variable load

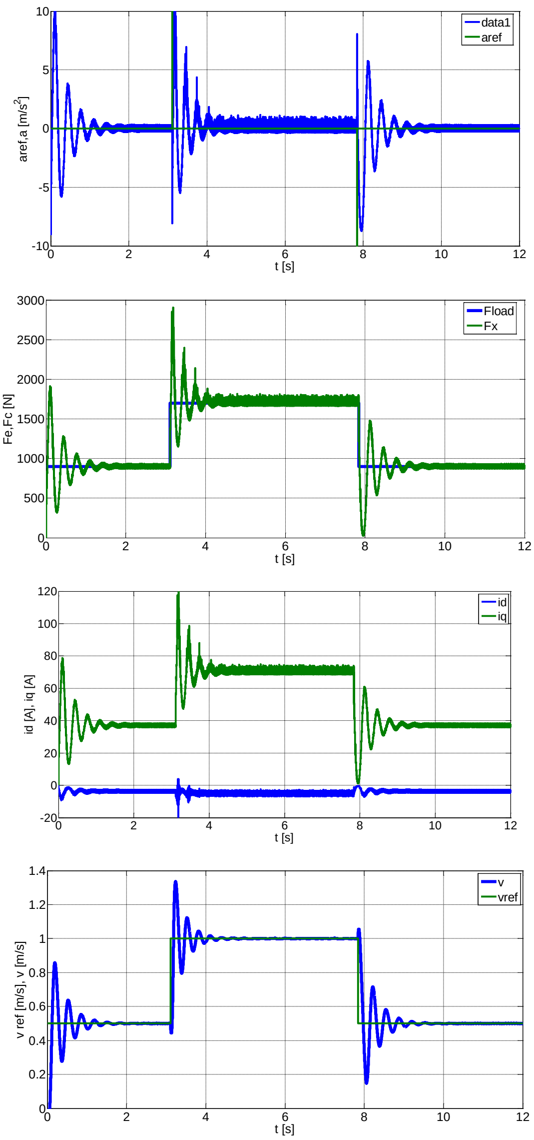

Fig. 10. Testing at variable speed and variable load

From simulations it can be seen that irrespectively of the reference speed and load, the engine is working job, and speed, and a force in the second half. The axis d current remains close to zero regardless of the load.

V. Conclusion

1. A simulation model of a control system of a linear synchronous motor with permanent magnets is developed.
2. The proposed control model can be used as a study basis for the dynamics of the linear synchronous motors with permanent magnets

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