Journal of Engineering and Applied Sciences 10 (8-12): 247-251, 2015
ISSN: 1816-949X

Computer Modeling of Combined Traction Levitation System Equipped with Linear Switched Reluctance Motors

Nikolay Grebennikov, Alexander Kireev and Gennady Kononov
Closed Joint-Stock Company, Scientific-Technical Center (PRIVOD-N),
Krivoshlykova Street 4a, 346428 Novocherkassk, Russia

Abstract: The study considers the development of computer modeling of combined traction levitation system equipped with linear switched reluctance motors. The given model makes it possible to realize the modeling of dynamic processes in phase circuits of traction levitation module, control algorithms of levitation and traction as well as system movement. The testing has demonstrated the ability of computer model to simulate the traction and levitation modes.

Key words: Traction levitation systems, combination of traction and suspension, linear switched reluctance machine, computer modeling, magnetic system

INTRODUCTION

Nowadays in Russia the interest in transport technologies based on contactless movement of objects through magnetic suspension has renewed. The main constraining factor for the development of high speed transport systems with magnetic suspension is their high cost. At the present time, the applied research is being conducted aimed at seeking the technical solutions to reduce the cost of systems' production through their simplification.

The transport system simplifying is connected with application of linear switched reluctance machines in traction levitation systems (Kireev *et al*., 2015). The possibility to apply this type of electric machine is determined by a large value of the normal component of force, generated by electromagnetic circuits which can be used to create the levitation and ensure the guidance. These machines are simple, technologically efficient, mechanically enduring and have low losses.

System simplification can be achieved by merging the functions of traction, levitation and guidance in the sin-gle power component Traction Levitation Module (TLM), the supply system which has a simple topological scheme and the discrete elements of the rotor track allow designing the passive track structure with lower materials.

All mentioned above allows us to predict the possibility of designing the simple combined traction levitation system for high speed vehicles with magnetic suspension applying well established techniques.

FUNCTIONAL SCHEME OF COMBINED TRACTION LEVITATION SYSTEM

Functional scheme of combined traction levitation system designed on the basis of linear switched reluctance motor is presented at Fig. 1. It contains power converter 1; control system 2; unit 3 taking into account the weight of the vehicle per one traction levitation module 4; coordinate measuring instrument 5; unit 6 taking into account the mass of the vehicle per one traction levitation module.

Under the influence of currents i_k, generated by power converter 1, traction levitation module 4 generates the lift force F_z and traction force in horizontal direction F_x. The lift force F_z provides the object levitation cancelling the object weight P and the effect of perturbing forces f_z. Under the action of traction force F_x the object is moved

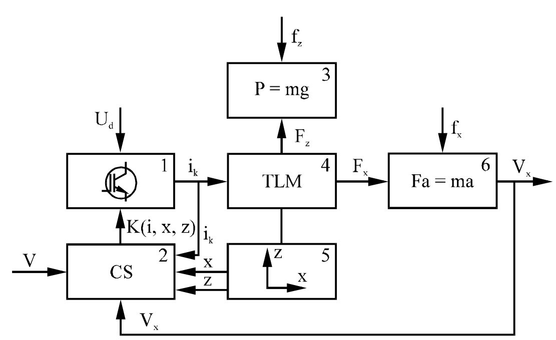

Fig. 1: Functional scheme of combined traction levitation system

Corresponding Author: Nikolay Grebennikov, Closed Joint-Stock Company, Scientific-Technical Center (PRIVOD-N), Krivoshlykova Street 4a, 346428 Novocherkassk, Russia

in horizontal direction against the force of inertia F_a and motion resistance force f_x. The coordinate measuring instrument 5 defines coordinates x and z of TLM 4 relatively to track structure. The control system 2 generates the switching function K(i, V, x, z) controlling the power keys switching of converter 1 which generates phase voltage u_k from supply voltage U_d for electromagnetic circuit of TLM in the way to ensure the object levitation and given speed of motion V in horizontal direction.

MATHEMATICAL MODEL OF COMBINED TRACTION AND SUSPENSION SYSTEM

The review of publications on the development of mathematical models of the systems with switched reluctance motors showed that the different approaches are used depending on the requirements to modeling results.

Most modeling accuracy is achieved by means of numerical solution of field problem at each iteration for the instantaneous values of phase currents and angular positions of the rotor (Rymsha *et al*., 2010). Currently, the application of this approach is constrained by the large amount of calculation.

More attractive way is to design the model based on equations drawing on the circuit theory. In this case, the equations are written in natural coordinate system by means of voltage and currents of actual coils. The reliability of modeling results is mainly defined by fidelity of magnetic characteristics obtained by carrying out of preliminary field calculation of motor magnetic system.

One of the directions of such approach is mathematical models based on the magnetic equivalent circuits (Kolomeitsev *et al*., 2008) which operate on a much smaller number of elements and allow us to combine the high performance and the required accuracy.

Another direction of this approach is based on the calculation of equivalent scheme of the motor phase circuit (Grebennikov and Kiereev, 2015). The characteristics of magnetic system are preliminary calculated and presented in the view of functional relationship of flux linkages of the phase motor against phase current and the displacement value between the axles of stator and rotor teeth. In this case, the phase circuits are considered as isolated from each other magnetically.

The peculiarity of mathematical model of combined traction and suspension system developed on the basis of circuit theory equations is the description of flux linkage of phase circuit as a function with three variables:

$$\Psi_k = f(i_k, x, z) \qquad (1)$$

Where:
x = Coordinate of horizontal movement
z = Coordinate of vertical movement
i_k = Current in the circuit

In general, the mathematical model is a system of equations describing the following:

- Voltage balance in electromagnetic circuits
- Processes of electromechanical energy conversion
- Object movement equations:

$$\begin{cases} u_k = i_k \cdot R + \dfrac{\partial \Psi_k(i_k, x, z)}{\partial i_k} \cdot \dfrac{di_k}{dt} + \dfrac{\partial \Psi_k(i_k, x, z)}{\partial x} \cdot \dfrac{dx}{dt} + \\ + \dfrac{\partial \Psi_k(i_k, x, z)}{\partial z} \cdot \dfrac{dz}{dt} \\ F_x = \displaystyle\sum_{k=1}^{b} \dfrac{\partial}{\partial x}\left(\int_0^i \Psi_k(i_k, x, z)di \right)_{\substack{i = const \\ z = const}} \\ F_z = \displaystyle\sum_{k=1}^{b} \dfrac{\partial}{\partial z}\left(\int_0^i \Psi_k(i_k, x, z)di \right)_{\substack{i = const \\ x = const}} \\ m \cdot \dfrac{d^2x}{dt^2} = F_x - f_x \\ m \cdot \dfrac{d^2z}{dt^2} = F_z - m \cdot g - f_z \end{cases} \qquad (2)$$

Where:
i_k = Phase circuit current
x = Coordinate of horizontal movement
z = Coordinate of vertical movement
Ψ_k = Flux linkage of phase circuit
k = Number of phase circuit
b = Quantity of phase circuits
g = Gravity acceleration
m = Levitating object mass
R = Active resistance circuit
u_k = The voltage applied to the phase circuit
F_x = Horizontal component of electromagnetic force
F_z = Vertical component of electromagnetic force
f_x = Motion resistance force
f_z = Perturbation effects

To prepare for computer modeling it is needed to perform a series of transformation in the equation system. In particular:

- To calculate the value of function $\Psi_k(i_k, x, z)$ and its partial derivatives at the interval of module pole pitch ($0<x<\tau$) under variation of value z

- To calculate the value of forces $F_{kx}(i_k, x, z)$ and $F_{kz}(i_k, x, z)$ at the interval of module pole pitch $(0<x<\tau)$ under variation of value z
- To present the partial derivatives of functions $\Psi_k(i_k, x(t), z)$ and $F_{kx}(i_k, x(t), z)$, $F_{kz}(i_k, x(t), z)$, calculated at the interval of pole pitch as periodic functions
- To introduce the function $Z_k(t)$, modeling the alternating signs behavior of flux linkage derivatives in the angle of electromagnetic circuit
- To introduce the switching function $K_k(t)$, modeling the curve of phase voltage
- To present the phase voltage as the following function

$$u_k = U_d \cdot K(i, V, x, z) \qquad (3)$$

where, U_d is power supply voltage. The differential equation, modeling the electromagnetic processes in the phase circuit, takes the form convenient for use in the computer modeling:

$$\frac{di_k}{dt} = \frac{1}{\frac{\partial \Psi(i_k, x, z)}{\partial i}} \cdot \Big(U_d \cdot K_k(i, V, x, z) - i_k \cdot R - \left(\frac{\partial \Psi_k(i_k, x, z)}{\partial x}\right) \cdot z_k(t) \cdot V - \frac{\partial \Psi_k(i_k, x, z)}{\partial z} \cdot \frac{dz}{dt}\Big) \qquad (4)$$

The mathematical model is focused on the use of Matlab Software. This has made it possible to design the computer model of combined traction and suspension system capable of developing the modeling of dynamic operation modes. This requires the preliminary field calculations of magnetic system of traction levitation module.

COMPUTER MODELING OF COMBINED TRACTION AND SUSPENSION SYSTEM

Based on the mathematical modeling of traction levitation system it has been designed its computer implementation in Simulink, the graphical environment simulation. The computer modeling is a structure consisted of functional, dynamic, algorithmic and structure units connected with links.

The special feature of the computer model is the use of expansion pack Simulink, Sim Power Systems for modeling of electric power systems. This package contains the ready models of power components (transistors, capacitors, switching units, sources, etc.) that make it possible to build the model of complex hybrid objects; particularly the model of power converter is built in the developed computer model. The models of power components are displayed as icons of their network analogs and connected by physical links which are the perfect conductive paths. This approach allows the user to describe the physical structure of the system. By means of system model scheme, Sim Power Systems automatically calculates the differential algebraic equations determining the system behavior. These equations are integrated into the rest part of Simulink Model (Fig. 2).

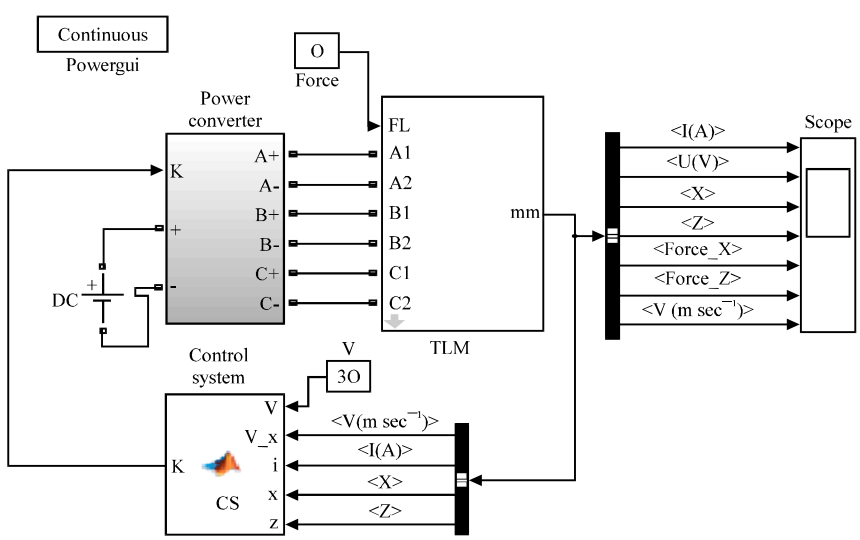

Fig. 2: Computer modeling of traction and suspension system

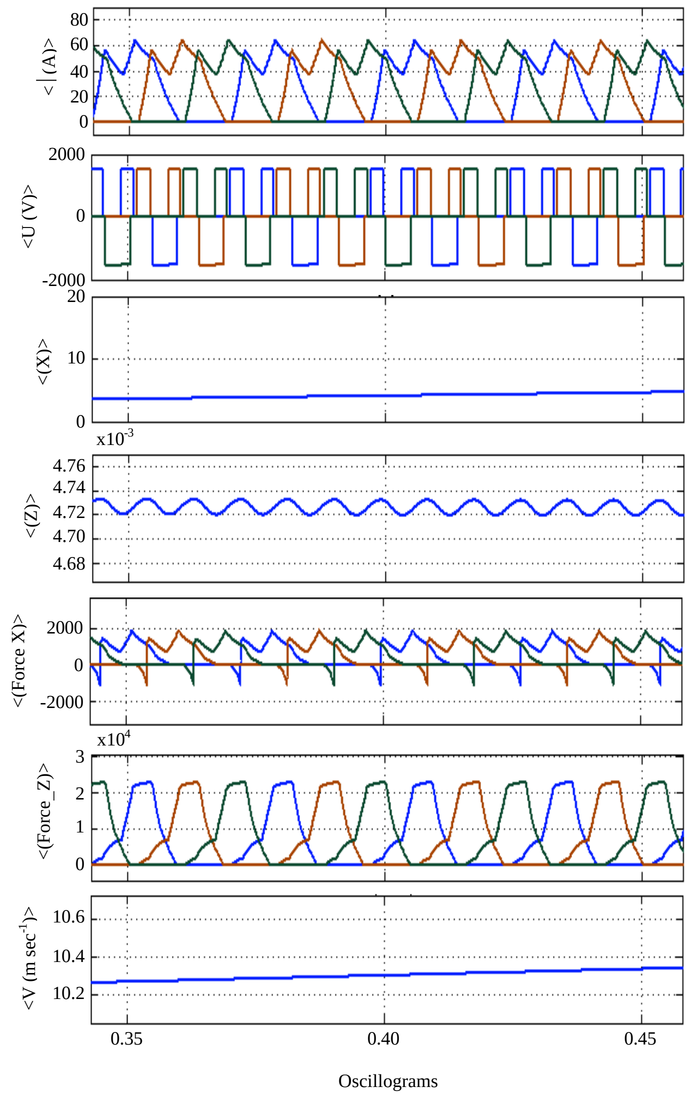

Fig. 3: Oscillograms of electromechanical activities in traction levitation system

The functional test of the computer modeling has been performed. Figure 3 shows the oscillograms of electromechanical activities in the system. Among other things, it is presented the oscillograms of instantaneous currents in the coils of traction levitation module as well as instantaneous forces to coordinates x, z.

It also presents the simulation test results of levitating module acceleration. From oscillogram, it follows that computer modeling is capable of simulating the dynamic operation modes. The test performed demonstrates the capability of computer modeling to simulate the traction, suspension and guidance modes.

CONCLUSION

The designed mathematical modeling of combined traction and suspension system and its computer implementation make it possible to realize the modeling of dynamic processes in electromagnetic circuits of traction levitation module, control algorithms of levitation and system movement. It allows us to perform the simulation experiments to research the processes in the system and to define its characteristics.

ACKNOWLEDGEMENT

The presented research has been developed with support of Russian Ministry of Education, grant RFMEFI57614X0040.

REFERENCES

Grebennikov, N.V. and A.V. Kiereev, 2015. Analytic model of electromagnetic processes in switched reluctance machines 18/15 configuration. J. Eng. Appl. Sci., 10: 28-32.

Kireev, A.V., N.M. Kozhemyaka and G.N. Kononov, 2015. Potential development of vehicle traction levitation systems with magnetic suspension. Int. J. Power Electron. Drive Syst., 6: 26-31.

Kolomeitsev, L., D. Kraynov, F. Pakhomin, F. Rednov and E. Kallenbach *et al*., 2008. Linear switched reluctance motor as high efficiency propulsion system for railway vehicles. Proceeding of the International Symposium on Power Electronics, Electrical Drives, Automation and Motion, June 11-13, Ischia, pp: 155-160.

Rymsha, V.V., I.N. Radimov, M.V. Guly and P.A. Kravchenko, 2010. Updated circuit-field model of switched reluctance motor. Electro tech. Electro Mech., 5: 24-26.