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MATHEMATICAL MODELING OF THE ELECTRIC DRIVE TURNOUTS BASED ON A LINEAR MOTOR

Abstract. *The article deals with the issues of improving the structure of the electric turnouts. A mathematical model of linear electromechanical transducer solutions based on Lagrange equation. The model can be used to determine the operating characteristics of the actuator in the further research work and turnout using a linear motor.*
Keywords: *electric turnouts, electromechanical system, the linear motor, the equation of Lagrange*

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МАТЕМАТИЧЕСКОЕ МОДЕЛИРОВАНИЕ ЭЛЕКТРОПРИВОДА СТРЕЛОЧНОГО ПЕРЕВОДА НА БАЗЕ ЛИНЕЙНОГО ДВИГАТЕЛЯ

Аннотация. *В статье рассмотрены вопросы совершенствования конструкции электропривода стрелочного перевода. Предложена математическая модель линейного электромеханического преобразователя на основе решения уравнения Лагранжа. Модель может быть использована для определения рабочих свойств рассматриваемого привода и дальнейшего исследования работы стрелочного перевода с использованием линейного двигателя.*
Ключевые слова: *электропривод стрелочного перевода, электромеханическая система, линейный двигатель, уравнение Лагранжа*

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МАТЕМАТИЧНЕ МОДЕЛЮВАННЯ ЕЛЕКТРОПРИВОДА СТРІЛОЧНОГО ПЕРЕВОДУ НА БАЗІ ЛІНІЙНОГО ДВИГУНА

Анотація. *У статті розглянуті питання вдосконалення конструкції електроприводу стрілочного переводу. Запропоновано математичну модель лінійного електромеханічного перетворювача на основі рішення рівняння Лагранжа. Модель може бути використана для визначення робочих властивостей розглянутого приводу і подальшого дослідження роботи стрілочного переводу з використанням лінійного двигуна.*
Ключові слова: *електропривод стрілочного переводу, електромеханічна система, лінійний двигун, рівняння Лагранжа*

Introduction

The task on modernization of the industry that Ukrainian Railways raised became the basis for the development and implementation of innovative systems or railway automation. The microprocessor equipment in comparison with relay analogues has essentially new functionality [1; 2; 4]. However, in practice, these opportunities aren't always realized in completely. Especially obviously this problem is shown in the field of control of electric drives. It is caused by insufficient theoretical study of the problems related with use of essentially new electric motors of linear type.

Problem definition of researches

Objective of the work is receiving mathematical model of the electric drive of the arrow translation on the basis of the linear engine LE [5; 8].

Material and results of researches

To solve this problem for the electromechanical system the system (Fig. 1) of the differential equations (1) which was received in the previous work [5] on the basis of Lagrange's equation was used.

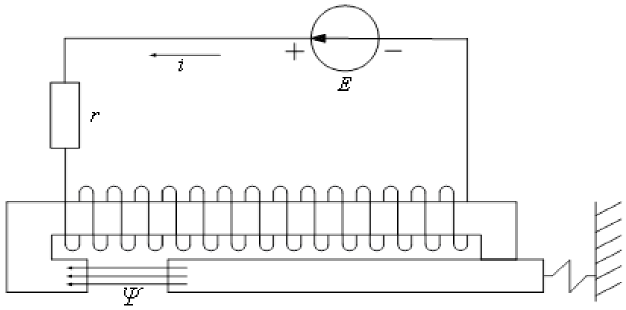


Fig. 1. Equivalent circuit of electromechanical system of the linear engine

$$\begin{cases} \dfrac{di}{dt} = \dfrac{1}{\dfrac{\partial \Psi(i,x)}{\partial i}} \left[E - \dfrac{\partial \Psi(i,x)}{\partial x} V - ir \right]; \\ \dfrac{\partial \left(\int\limits_0^i \Psi(i,x) di \right)}{\partial x} - \alpha V - F_C + 2F_{\Pi P} = m \dfrac{dV}{dt}; \\ \dfrac{dx}{dt} = V. \end{cases} \quad (1)$$

where $i-$ current in the stator winding; $\Psi(i,x)-$ flux linkage of the stator; $E-$ EMF of the power source; $r-$ the resistance of the stator windings; $V-$ the speed of the movement of an anchor; $\alpha-$ the coefficient of friction between directing and an anchor; F_C- the resistance force; $F_{\Pi P}-$ the spring force; $x-$ movement of an anchor.

The system of equations (1) is a mathematical model of LE. For identification of its parameters it is necessary to establish dependences between flux linkage $\Psi(i,x)$, on the one hand, the generalized coordinates and their derivatives on the other hand. For this purpose we offer to make a complex of digital experiments and to define these dependences. For determination of value of flux linkage it is offered to carry out calculation of the magnetic field of the LE in two-dimensional statement with use of a method of final elements for a plane-parallel task. By results of the analysis of a magnetic field it is possible to define values of flux linkage $\Psi(i,x)$ of LE and value of electromagnetic force.

For the solution of an objective the program FEMM complex was used, which includes:

– the preprocessor, which allows to set boundary conditions, properties of materials of settlement areas and the program of a triangulation;

– the program of calculation of the magnetic field, which constitutes and solves the system of nonlinear equations by the Newton-Raphson's method;

– the post-processor which allows to display the calculated picture of a magnetic field, to calculate of surface integrals of various types, to count integrals on the set contour, to define the magnetic flux which passes through the set contour, to define the values of intensities, magnetic field induction in the set points, the magnetic permeability in the set points.

On a Fig. 2 the area of calculation, which is divided into triangular finite elements, and the picture of the magnetic circuit lines with a maximum gap and nominal current in the coil are presented.

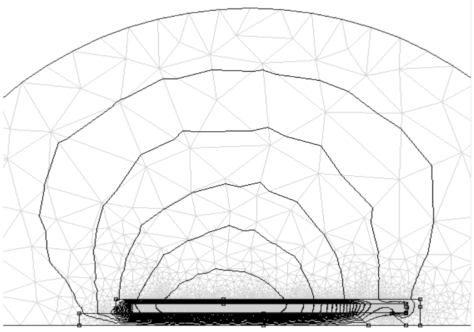
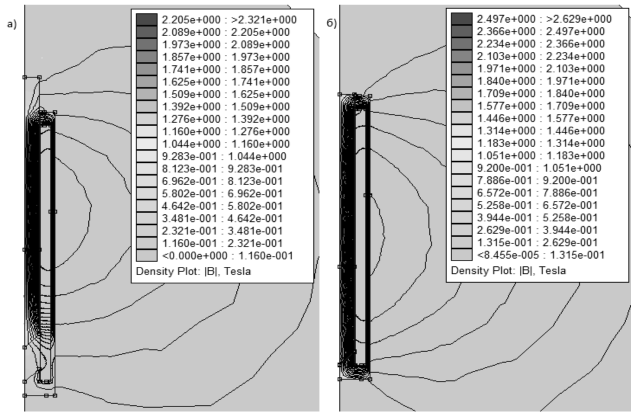


Fig. 2. Area of calculation and the image of the magnetic field with the maximum gap

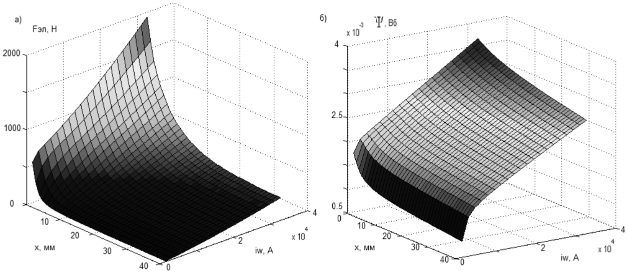
The distribution of the magnetic field in the calculation scheme of LE at the maximum and zero gap and the values of magnetic induction for various areas of machine (the right of models) are shown in Fig. 3.



a b

Fig. 3. The distribution of the magnetic field in the LE: a – gap 40 mm; b – gap 0 mm

The calculation was carried out using the subroutine written in the text file in the Lua language. Boundary area of this calculation was the anchor position - from 40 to 0 mm. Distribution of electromagnetic force and flux linkage in form surfaces are presented in Fig. 4.



a b

Fig. 4. Results of digital modeling: a – electromagnetic force; b – flux linkage

For obtaining continuous dependences of flux linkage and the electromagnetic force results of digital modelling are offered to be approximated with power functions for determination of coefficients of regression it is offered to use a method on the basis of Chebyshev's polynomials. Curves of change of force for the calculated values by the program and for values on a polynomial are shown in Fig. 5.

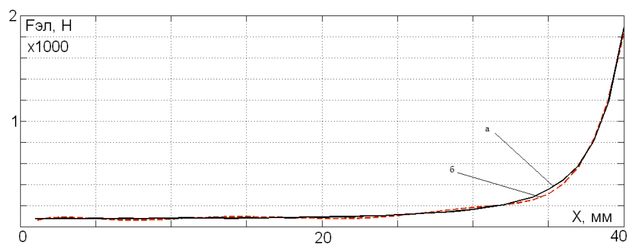


Fig. 5. The curves of change of the electromagnetic force: a – for the values of FEMM; b – for the values of a polynomial

On the basis of the differential equations (1) and resulting from the approximation of the continuous dependence of flux linkage and the electromagnetic force the block diagram of the electric drive with LE was constructed (Fig. 6)

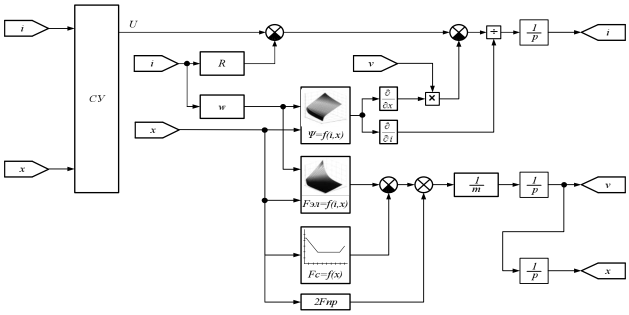


Fig. 6. The block diagram of the electric drive with LE

Mathematical formulas of force of resistance and total force of two springs operating in system were described in [5].

Results of researches of mathematical model of the electric drive are the received dynamic characteristics which describe change of current of the engine (Fig. 7), the traction force of the electric drive (Fig. 8), speed (Fig. 9) and movement (Fig. 10) of an edge.

The start mode the engine with current limitation is required to regulate the speed of translation of the arrow, thus the scheme of control generates a PWM signal.

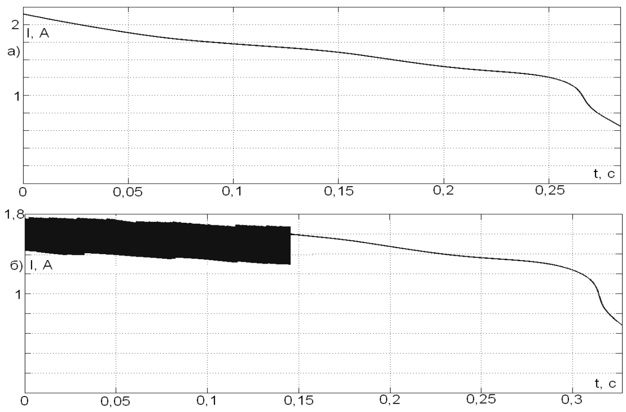


Fig. 7. Characteristic of current of the engine:
a – direct start; b – with current limitation

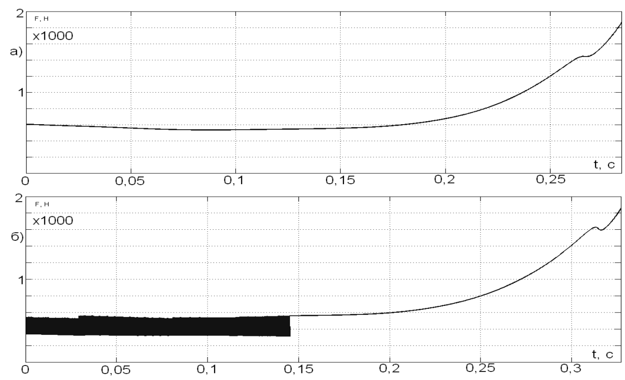


Fig. 8. Characteristic of traction force of the electric drive: a – direct start; b – with current limitation

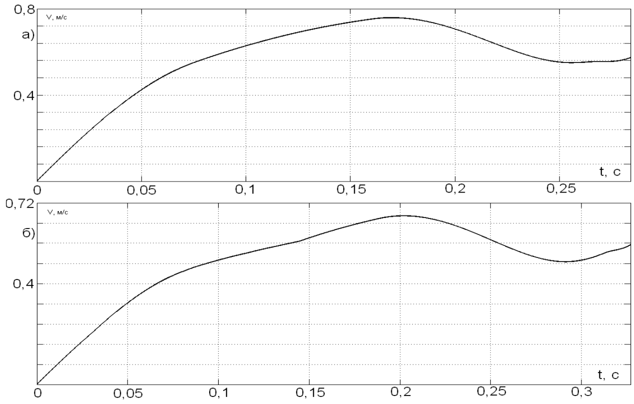


Fig. 9. Characteristic of speed of the movement of the edge: a – direct start; b – with current limitation

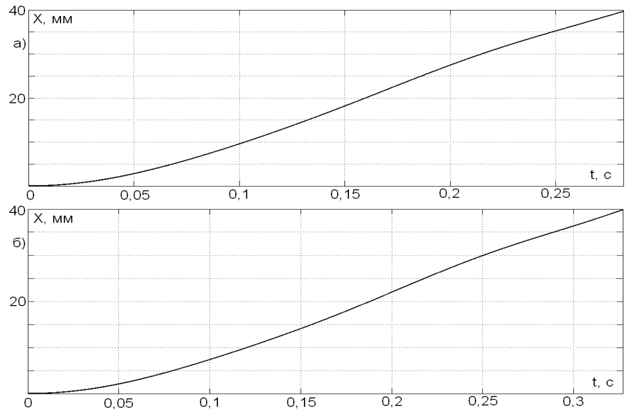


Fig. 10. Characteristic of movement of the edge:
a – direct start; b – with current limitation

Results of modelling show opportunity and prospects of use of the linear engine as drive for the arrow displacement.

Conclusions

The developed mathematical model of the electromechanical converter on the basis of the solution of the equation of Lagrange for electromechanical system allows considering mutual influence of streams from windings of various phases. Such model can be used for determination of working properties of the considered drive. Also obtained a mathematical model can be used as universal for any linear electromechanical converter.

The simulation model allows modelling the dynamic processes occurring both in the drive in and in its individual links, work regulations laws and to investigate the influence of parameters of individual elements of the processes of electromechanical transformation of energy.

Results of modelling confirm the solution of an important question of ensuring necessary traction force at the initial moment of the displacement (Fig. 8). These dynamic characteristics show the possibility of reducing the speed of the displacement of arrow down to less than 0,5 seconds.

On the basis of mathematical model synthesis of a control system for the arrow displacement with the linear engine is possible.

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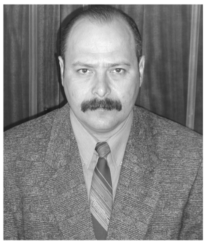

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