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UDC 531

SIMULATION OF DC ELECTRIC MOTOR WITH INDEPENDENT EXCITATION

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Abstract. *A DC motor with independent excitation is considered. Based on the apparatus of analytical mechanics, correct mathematical models are presented, which contain differential equations of mechanical motion, as well as equations of electromagnetic processes. Electromagnetic and mechanical quantities characterizing the movement of systems appear as formally equal. Considering the complexity of the systems, the research was carried out using computer technology. As a result, dependencies were obtained and graphs of changes in system parameters over time were constructed.*

Key words: *electromechanical system, Lagrange-Maxwell electromechanical analogies, nonlinear dynamics.*

Introduction.

Electromechanical systems (EMS) are widely used in many fields of technology. Electric motors, generators, non-contact (electromagnetic, electrostatic) suspensions of a solid body, electrical measuring devices are various examples of electromechanical systems. are widely used in many fields of technology. The development of EMC goes both along the path of improving technical means and in the direction of finding new control algorithms. For rational design and further analysis of the properties of such systems, modern engineering practice requires the creation of correct mathematical models, which must contain differential equations of mechanical motion, as well as equations of electromagnetic processes. The apparatus of analytical mechanics is very convenient for compiling the equations of electromechanical systems, in which the electromagnetic and mechanical quantities characterizing the system appear as formally equal and the equations of motion are derived using the Lagrangian formalism [1-4].

The purpose of this work is to develop and study complex dynamic models of direct current systems based on Lagrange-Maxwell electromechanical analogies.

Main text.

Consider a direct current electric motor with independent excitation set in motion by the input link of the mechanism for which the moment of inertia $J_П$ is given. The inductances of the excitation windings and the rotor armature are L_B and $L_Я$, and their mutual inductance is $M(\varphi)$. Assuming that $J_П$, $M(\varphi)$ and the reduced moment of forces, etc. $M_{пр}$ are given functions of the angle φ of rotation of the armature of the electric motor.

If we consider the current i_B in the excitation winding to be constant, then the state of the electromechanical system is determined by two generalized coordinates - the angle φ of the armature rotation and the charge corresponding to the current $i_Я$ in the armature winding

$$q_1 = \varphi, \quad q_2 = q_э = \int_0^t i_Я \cdot dt \,.$$

For such a two-stage electromechanical system, we have the following Lagrange-Maxwell equations:

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{\varphi}}\right) - \frac{\partial T}{\partial \varphi} = Q_\varphi, \quad \frac{d}{dt}\left(\frac{\partial T}{\partial \dot{q}_э}\right) - \frac{\partial T}{\partial q_э} = Q_q \,.$$

The kinetic energy of the considered electromechanical system is equal to the sum of the kinetic energy TM of the mechanical part of the system and the energy of the magnetic field TE of the electric circuit. Ago

$$T = T_M + T_Э = \frac{1}{2}\left[J_z \cdot \dot{\varphi}^2 + L_B \cdot i_B^2 + L_Я \cdot i_Я^2 + 2M(\varphi) \cdot i_Я \cdot i_B\right].$$

To find the generalized force Q_φ, let's give the armature of the electric motor a virtual angular displacement $\delta\varphi$, while considering the electric charge q_e to be constant. We have

$$\delta A_\varphi = M_{np} \cdot \delta\varphi, \text{ so, } Q_\varphi = M_{np}.$$

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When calculating the generalized force Q_q we will assume that the electric charge q_e will change, and the anchor will remain stationary, that is, $\delta q_e \neq 0$, $\delta\varphi = 0$. At the same time, virtual work is equal

$$\delta A_q = (U - i_Я \cdot R) \cdot \delta q_e,$$

where U is the voltage applied to the armature winding, R is the resistance of this winding.

Therefore, the generalized force Q_q, corresponding to the chosen generalized coordinate q_e, is an expression

$$Q_q = U - i_Я \cdot R.$$

Let's calculate the necessary derivatives of the kinetic energy of the considered system, assuming that the inductances L_B and $L_Я$ are constant, and the mutual inductance $M(\varphi)$ depends on the angle of rotation of the armature of the electric motor

$$\frac{\partial T}{\partial \dot{\varphi}} = J_П \cdot \dot{\varphi}, \quad \frac{d}{dt}\left(\frac{\partial T}{\partial \dot{\varphi}}\right) = J_П \cdot \ddot{\varphi} + \dot{\varphi}^2 \cdot \frac{\partial J_П}{\partial \varphi},$$

$$\frac{\partial T}{\partial \varphi} = \frac{\partial M(\varphi)}{\partial \varphi} \cdot i_Я \cdot i_B + \frac{1}{2}\dot{\varphi}^2 \cdot \frac{\partial J_П}{\partial \varphi}, \quad \frac{\partial T}{\partial q_э} = 0,$$

$$\frac{\partial T}{\partial \dot{q}_э} = \frac{dT}{di_Я} = L_Я \cdot i_Я + M(\varphi) \cdot i_B, \frac{d}{dt}\left(\frac{\partial T}{\partial i_Я}\right) = L_Я \cdot \frac{di_Я}{dt} + \frac{\partial M(\varphi)}{\partial \varphi} \cdot \dot{\varphi} \cdot i_B.$$

By substituting the derived and generalized forces into the Lagrange-Maxwell equation, we will obtain the desired dynamics equations of the electromechanical system under consideration:

$$\begin{aligned} & J_П \cdot \ddot{\varphi} + \frac{1}{2} \cdot \dot{\varphi}^2 \cdot \frac{\partial J_П}{\partial \varphi} - \frac{\partial M(\varphi)}{\partial \varphi} \cdot i_Я \cdot i_B = M_{пр}, \\ & L_Я \cdot \frac{di_Я}{dt} + \frac{\partial M(\varphi)}{\partial \varphi} \cdot \dot{\varphi} \cdot i_B = U - i_Я \cdot R. \end{aligned} \qquad (1)$$

Let's find the numerical solution of system (1) in Matlab. To do this, we will reduce system (1) to a system of differential equations of the first order. For this, we will introduce functions $y_1(t) = \varphi(t)$, $y_2(t) = \dot{\varphi}(t)$, $y_3(t) = i_Я(t)$. Тоді систему (1) можна записати у вигляді

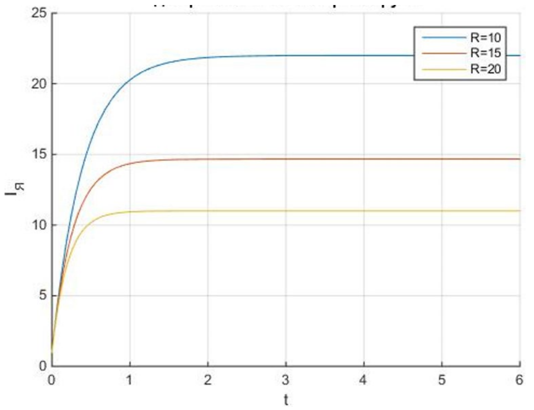
$$\frac{dy_1(t)}{dt} = y_2(t)$$

$$\frac{dy_2(t)}{dt} = \frac{M_{пр}\left(y_1(t)\right)}{J_П\left(y_1(t)\right)} - \frac{y_2^2(t)\dfrac{\partial J_П\left(y_1(t)\right)}{\partial y_1}}{2J_П\left(y_1(t)\right)} + \frac{\dfrac{\partial M\left(y_1(t)\right)}{\partial y_1} y_3(t) i_B}{J_П\left(y_1(t)\right)}$$

$$\frac{dy_3(t)}{dt} = \frac{1}{L_Я}\left(U - y_3(t)R\right) - \frac{1}{L_Я}\frac{\partial M\left(y_1(t)\right)}{y_1} y_2(t) i_B$$

As the dependence of the moment of inertia $J_П$ on the angle φ, the dependence of the type $J_П(\varphi) = J_0 + k_{\max}\sin(\varphi)$ corresponding to the crank-rod mechanism was chosen. The function $M_{пр}(\varphi)$ was considered equal $M_{пр}(\varphi) = \exp(-\varphi)$, mutual inductance $M(\varphi) = M_{\max}\cos(\varphi)$.

In fig. 1-2 shows the dependence of the armature current $i_Я$ on time t for different values of the resistance R and the inductance $L_Я$ of the armature winding.



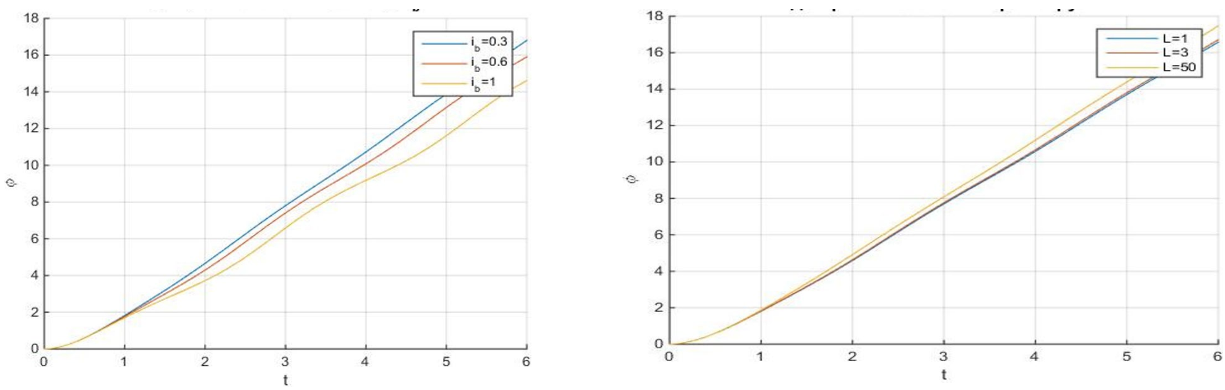
a) *b)*

Figure 1 - Dependence of the armature current $i_Я$ on time *t* for different values of the resistance *R (a)* of the inductance $L_Я$ (*b*) of the armature winding.

From fig. 1,*a*) it can be seen that after the completion of the transient process, the current value acquires a constant value, which decreases with increasing *R*. As the inductance $L_Я$ of the armature winding increases, the duration of the transient process increases, and the current value does not change, as shown in Fig. 1,*b*).

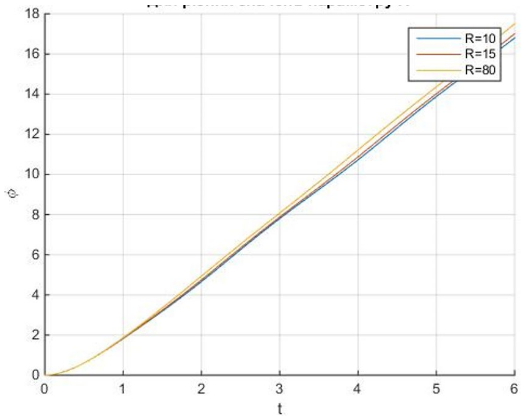
In fig. 2 shows the dependence of the angle of rotation of the armature φ and the angular velocity ω on time *t* for different values of the resistance *R* , the inductance $L_Я$ of the armature winding and the current i_B in the excitation winding.

It can be seen from Fig. 2 d), e), f) that after the completion of the transient process, the angular velocity oscillates around a constant value. The presence of oscillations is related to the existing dependence of the moment of inertia $J_П$ on the angle of rotation of the armature φ. The amplitude and period of oscillations depend on the resistance *R*, the inductance $L_Я$ of the armature winding and the current i_B in the excitation winding, and i_B it affects these characteristics more than *R* and $L_Я$. The angle of rotation of the armature φ increases with increasing *t*, which can be seen from Figure 2 a), b), c). An increase in φ indicates that the rotation is in one direction.

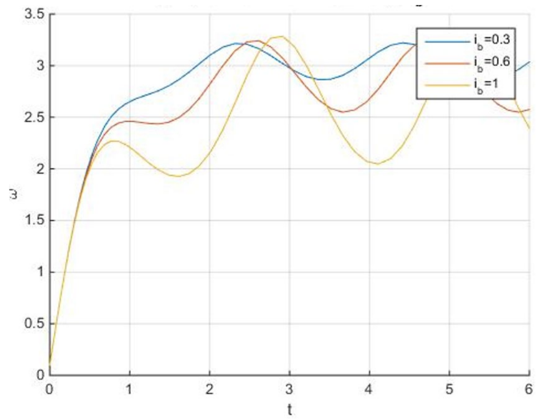


a) a) dependence of the angle of rotation of the armature φ on time *t* for different values of the current i_B in the excitation winding.

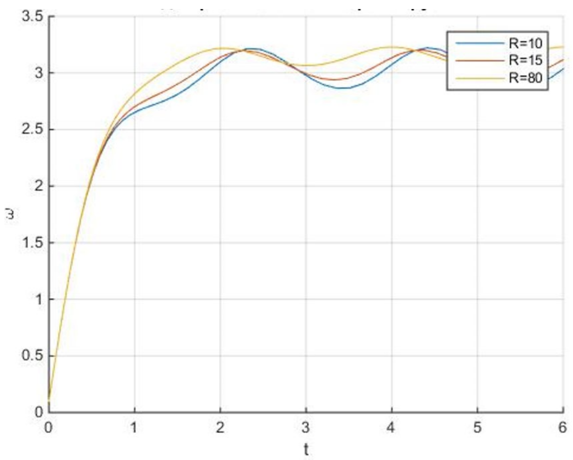
b) dependence of the angle of rotation of the armature φ on time *t* for different values of the inductance $L_Я$ of the armature winding



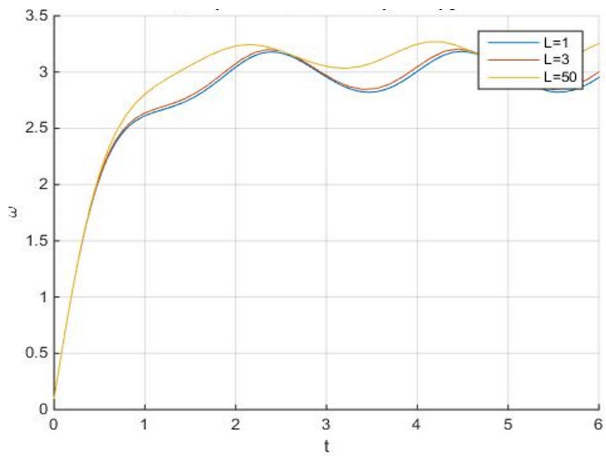
c) dependence of the angle of rotation of the armature φ on time t for different values of the resistance R in the excitation winding.



d) dependence of angular velocity ω on time t for different current i_B values in the excitation winding.



e) the dependence of the angular velocity ω on time t for different values of the resistance R in the excitation winding.



f) dependence of the angular velocity ω on time t for different values of the inductance $L_Я$ of the armature winding.

Figure 2 – Dependence of the angle of rotation of the armature φ and the angular velocity ω on time t

The nonlinearity of the $\varphi(t)$ dependence indicates the presence of angular velocity oscillations.

Summary and conclusions.

Have been considered DC electric motor with independent excitation is set in motion by the input link of the mechanism on the basis of Lagrange-Maxwell electromechanical analogies.

Were received dependence of the armature current on time for different values of the inductance resistance of the armature winding. The dependence of the angle of rotation of the armature and the angular speed on time for different values of resistance, inductance of the armature winding and current in the excitation winding were obtained.

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