ГІРНИЧА ЕЛЕКТРОМЕХАНІКА

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ENERGY PROCESSES IN THE SYSTEM OF CONTROLLED STORAGE CONDENSER – DC MOTOR

Railway transport – is not only products consumer of the fuel and energy complex, but at the same time the technological branch in the circle of production, transmission and consumption of electricity. The cost of traction trains circles constitutes the main part of energy expenses of electrified railways. In the case of the last determines it is actual to introducing relevance of resource and energy-saving technologies in the electricity consumption system of electrical traction complex.

One of the main causes of energy costs increasing in locomotive electrical traction complex is irregular schedule and irregular power consumption mode of each electromotive composition unit [1]. The irregularity energy consumption problem in the electrical traction complexes does not disappear even with usage regenerative braking mode for partial reimbursement of primary energy in the network with using the inverter for traction substations [2]. The most effective solution to the problem of inconsistency in the modes of power supply and the consumer is possible by energy storage devices, which allow to separate in the time necessary portions of generated and consumed power [3].

The technical solutions of the increasing the power consumption quality of traction electro technical complex are widespread due to reactive power compensation [4], and also due to the accumulation of electrical energy [5]. The authors reviewed the functioning of the proposed generalized solutions [6] and energy performance for specific technical parameters of locomotive [7]. Questions of the modeling modes and the study of energy processes in the system storage device – the engine are considered insufficient.

The purpose of the work is development of mathematical model and study of energy processes in the system of controlled capacitor storage device – DC motor.

The electric locomotives and the electric trains have high economic indicators and the number of technical advantages over other types of locomotives. Most common on the railway network became the serial two-section electric locomotives of VL80 all versions, which are equipped with collector traction motors. This type of locomotive is a major freight locomotive of the electrified AC railway lines with voltage of 25 kV and frequency of 50 Hz. These locomotives originally built with the settings that convert high voltage AC to DC pulsating current lower voltage with usage of traction transformer and ignitron rectifiers, and then with the silicon rectifiers.

Regenerative braking modes and implemented devices in a series of VL80 realized in the "r" modification which the usage rectifier-inverter converter RIC [8]. VL80r is one of the latest series versions.

The main complication of using regenerative braking mode is not converting kinetic energy into electrical energy and returns it to the contact network, but the ability of the network to take this additional energy. It is possible with the energy consumption from network by other devices in the traction mode or by transferring it into a three-phase AC power. For that it is necessary to convert the DC voltage into three-phase synchronized with the network frequency and amplitude.

All these drawbacks can be eliminated by the equipping traction with substations capacitive storage that used to excess braking energy to return it in a contact network at start and dispersal of trains [9]. It is not excluded losses in the network.

Fig. 1 shows the scheme of the proposed device for the dynamic modes realization of traction complex of electric locomotives. This system allows providing the storage of excess energy which produced during braking motor in the condenser storage and its future using it in dispersal mode.

In stationary mode power of armature motor windings perform by thyristor rectifier-inverter converter, connected by voltage transformer with AC network through collector (pantograph).

Rectifier excitation setting supplies close to the nominal current on winding of traction motors. At a constant speed of rotation and direct current of winding excitation of traction motors range of armature windings induce DC electromotive.

In the dynamic mode for the realization of deceleration (acceleration) thyristor rectifier-inverter converter is blocked by terminating the formation of control pulses. Control block of the capacitor energy storage based on the current values of current and voltage of armature winding and current of capacitor energy storage generates the control signal on output [10].

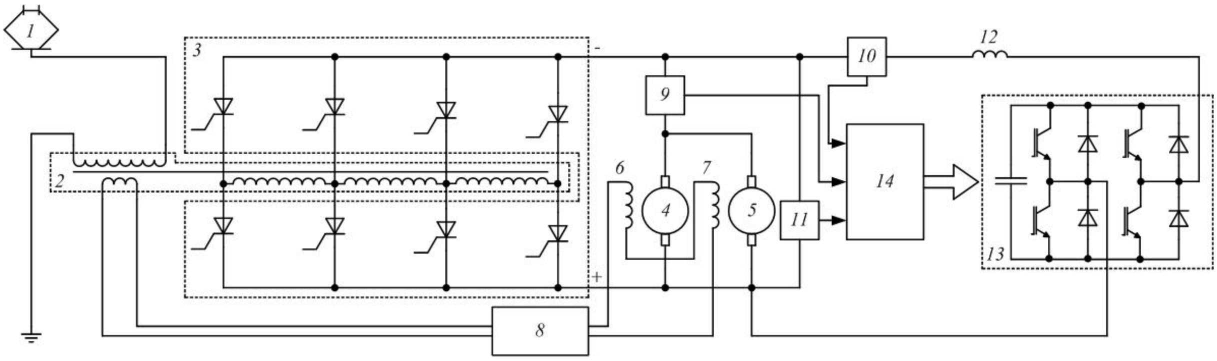


Fig. 1. A system for the realization dynamic modes of traction complex of electrical locomotive:
1 – pantograph; 2 – voltage transformer; 3 – thyristor rectifier-inverter converter;
4 – armature winding of the first traction motor; 5 – armature winding of the second traction motor;
6 – excitation winding of the first traction motor; 7 – excitation winding of the second traction motor;
8 – rectifier excitation setting; 9 – current sensor of traction motors;
10 – current sensor of the capacitor energy storage; 11 – voltage sensor of motors; 12 – reactor;
13 – capacitor energy storage; 14 – control block of capacitor energy storage

In this case control signal of capacitor energy storage formed by on the errors:

$$\Delta I_{ces} = i_{ces}^{set} - i_{ces}\,, \tag{1}$$

where i_{ces}^{set} – set current value; i_{ces} – current value of the current of capacitor energy storage.

Under this voltage of capacitor energy storage u_{ces} is:

$$u_{ces} = \begin{cases} 1,\ при\ \left(\Delta i_{ces} > HB, \dfrac{di_{ces}}{dt} > 0\right) \cap \left(\Delta i_{ces} > -HB, \dfrac{di_{ces}}{dt} < 0\right) \\ -1,\ при\ \left(\Delta i_{ces} < -HB, \dfrac{di_{ces}}{dt} > 0\right) \cap \left(\Delta i_{ces} > HB, \dfrac{di_{ces}}{dt} > 0\right) \end{cases}. \tag{2}$$

This provides the switching of power switches of capacitor energy storage, when the error exceeds a fixed value – zone of hysteresis ($HB = 0{,}05 i_{ces}^{set}$). In this case positive values correspond to deceleration and negative – acceleration. Critical capacitor voltage reduction can compensated by its charging by thyristor converter in static mode.

On the base of the circuit (fig. 1) in the Matlab environment was developed a mathematical model of electrical traction complex of one locomotive section for studies energy processes in static and dynamic modes (fig. 2).

Real DC traction motors NB-418K6 power of 790 kW and a supply voltage of 950 V represented by block DC machine in a mathematical model. Ports of model A + and A- are armature winding outputs of machine and port F + and F- – excitation winding outputs. Ports TL intended for giving the resistance movement moment. At the output port m vector signals have generated have which reflect the engine output parameters: rotational speed, armature current, the excitation current and electromagnetic torque of machines [11]. Armature windings of electrical machines (DC1, DC2) are connected in parallel, the voltage is controlled by the armature block VC. Excitation windings connected to individual sources of constant voltage (V1, V2). Power of armature circles is carried out block V3 through the thyristor (GTO). Additionally, to reduce high-frequency pulsations introduced a passive filter RC.

Controlled storage device which includes transistors VT1-VT4, capacitor C_b and inductance L_b connected in parallel with armature circles of electrical machines. Controlling of the transistors is carried out by block Control System (fig. 3) with the current AC i_{ces}, which is measured by block CC.

A trajectory of speed change is given in the block Control System. On the basis of considering resistance coefficient k_{mec} and the reduced moment of inertia J_{Σ} is determined a given current:

$$i_{ces}^{set} = \left[J_{\Sigma} \frac{d\omega}{dt} + k_{mec}\omega \right] \frac{1}{k\Phi}\,, \tag{3}$$

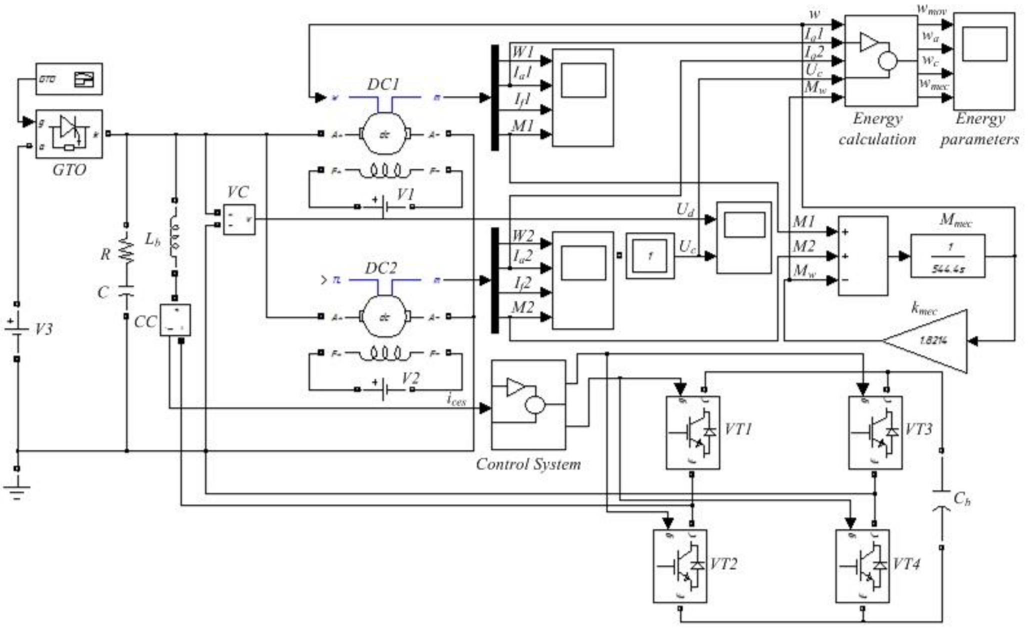


Fig. 2. Mathematical model of electrical traction complex of one electric locomotives section

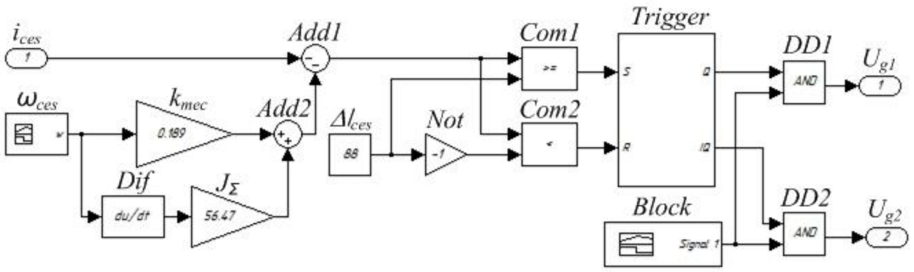


Fig. 3. Structure of impulse control system Control system

where k_{mec} – mechanical resistance coefficient of motors; J_Σ – reduced inertia moment of motors; $k\Phi$ – magnetic flux of motors.

Using the obtained value of the current i_{ces}^{ref} and present current i_{ces} according to expressions (1) and (2) generated transistors control voltage U_{g1} and U_{g2}, which by necessity are blocked due to logic elements DD1 and DD2 at the command the element Block.

The block calculation of energy parameters Energy calculation (fig. 4) additionally introduced in the model, which calculate:

– energy moving masses of electric locomotives $W_{mov} = J\omega^2/2$;

– energy of capacitor $W_c = CU^2/2$;

– energy losses of armatures $W_a = I^2 R$;

– useful mechanical energy $W_{mec} = \int M\omega dt$.

During the modeling assigned: all valves – perfect switchers with one-sided conductivity; pulsation the rectifier and its output current is relatively small with a constant component; voltage, current and rotation frequency of the armature are connected in accordance with the recommendations of the expressions [12]:

$$\begin{cases} U_a = L_a \dfrac{di_a}{dt} + i_a R_a + \omega_a k\Phi \\ i_a = \dfrac{1}{k\Phi}\left(J \dfrac{d\omega_a}{dt} + k_m \omega_a \right) \end{cases}, \tag{4}$$

where U_a – armature voltage ; L_a – armature inductance; i_a – armature current; R_a – armature resistance; ω_a – rotational speed of the armature.

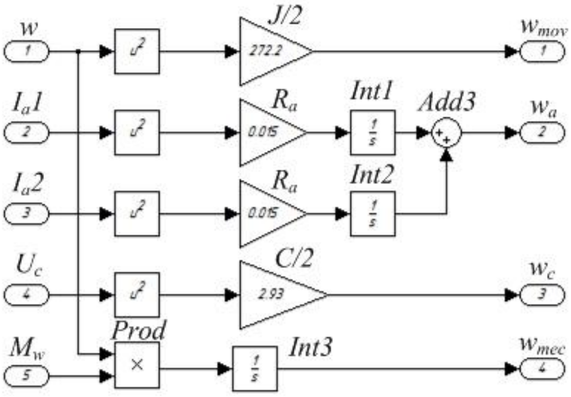


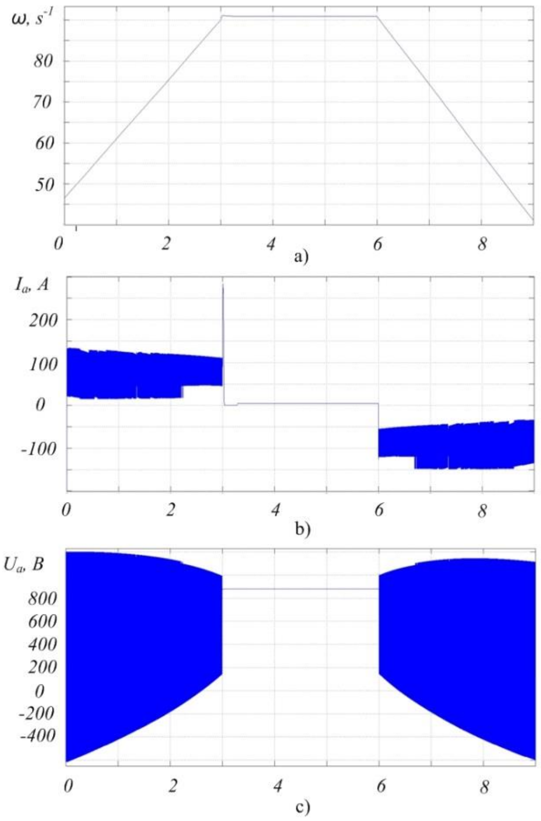
Fig. 4. The system for determining the energy performance of electric locomotives

In the operating mode of the converter VT1-VT4 $U_{g1}+U_{g2}=1$. Thus the mode parameters of converter are connected as follows:

$$\begin{cases} L\dfrac{di_{ces}}{dt}=U_a-U_{ces\ in}=U_a-U_{g1}U_{c\ ces} \\ C\dfrac{du_{c\ ces}}{dt}=i_{c\ ces}=U_{g1}i_{ces} \end{cases}, \qquad (5)$$

where $U_{ces\ in}$ – input voltage of capacitor energy storage; $i_{ces\ in}$ – input current of capacitor energy storage.

Fulfilled modeling of speed change mode according to fig. 5, a and received the time dependence of the armature voltage and current (fig. 5, b, c), and change of energy (fig. 6). In this case, the following parameters of the capacitor energy storage were installed: $L_b=L_a=0{,}2$ mH; $U_{cb}=2{,}2U_a=1995$ V; $C_b=0{,}225$ F.



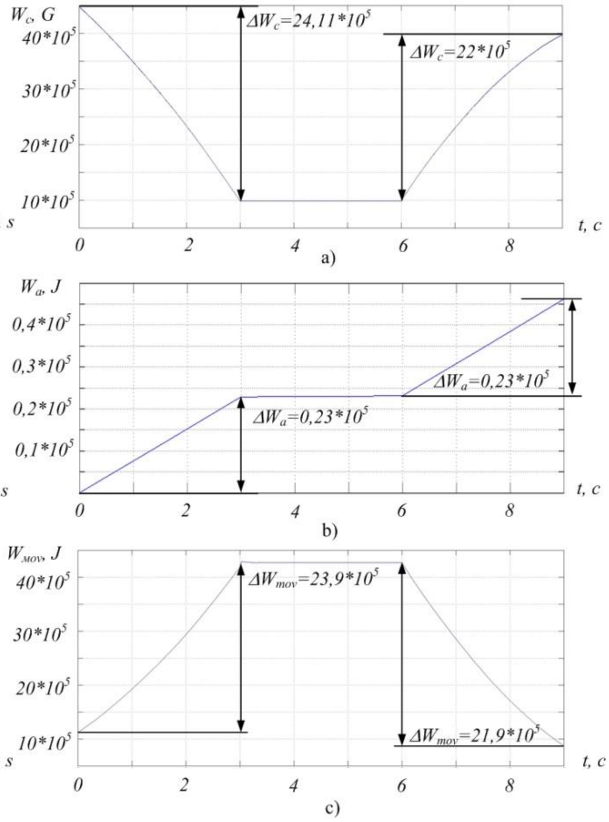


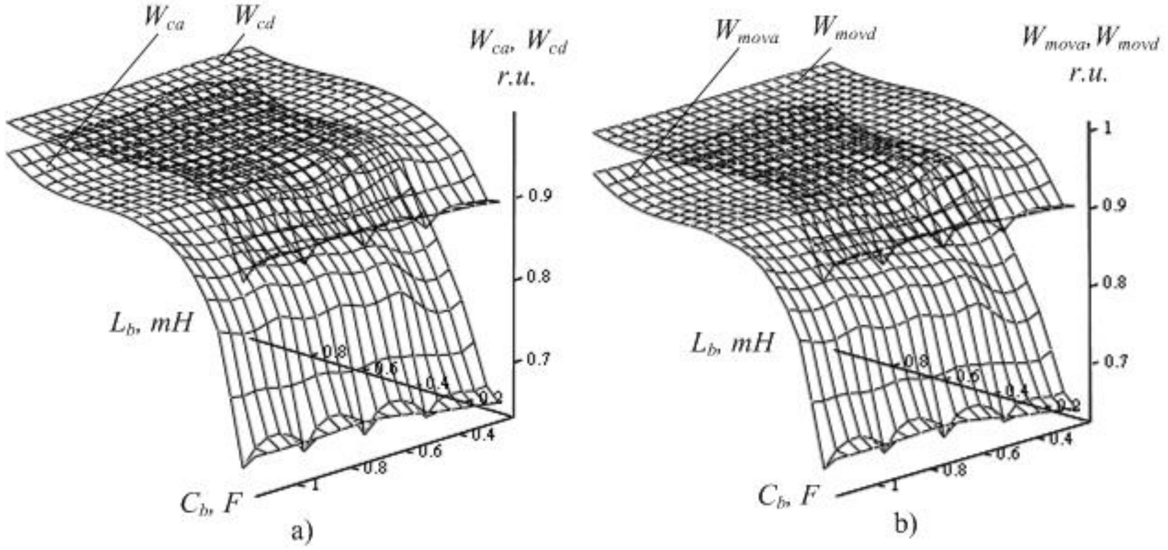
Fig. 5. Graphs of motors transient processes:
a – rotation frequency; b – current;
c – voltage

Fig. 6. The energy performance of the system:
a – capacitor energy; b – armature losses;
c – useful mechanical energy

The energy performance were researched to determine the effect scheme parameters of capacitor energy storage on the efficiency of mode by changing ΔI_{ces}, L_b and C_b. There were the following groups of experiments:

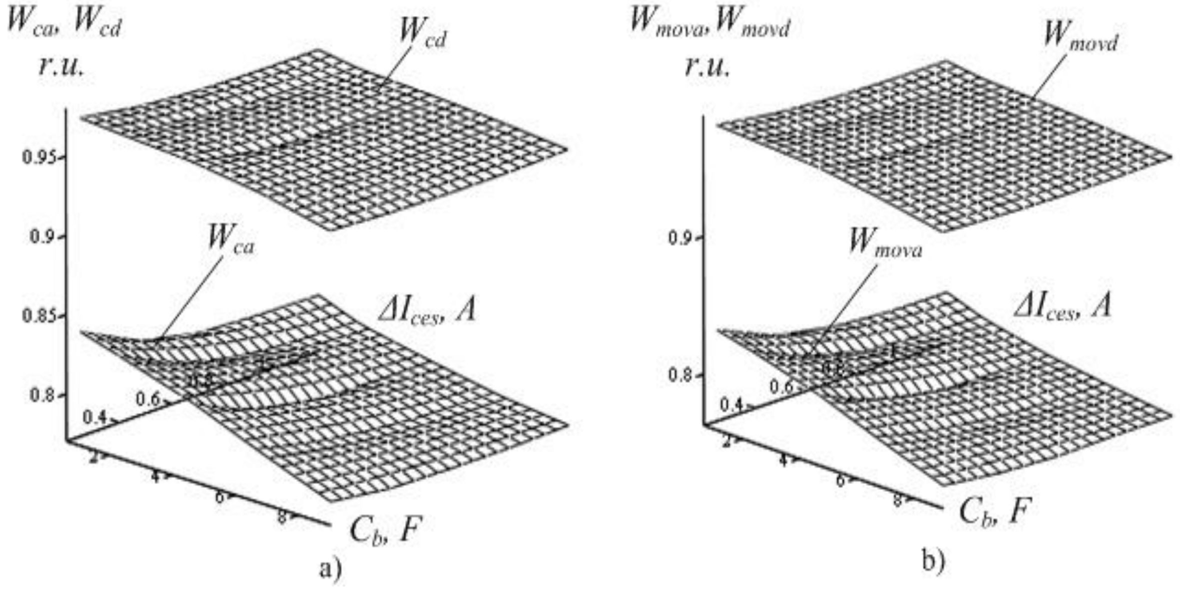
1. $\Delta I_{ces} = const = 0{,}88$ A, $L_b = 0{,}04...1$ mH, $C_b = 0{,}225...1{,}125$ F.
2. $\Delta I_{ces} = 0{,}08...8{,}8$ A, $L_b = const = 0{,}2$ mH, $C_b = 0{,}225...1{,}125$ F.
3. $\Delta I_{ces} = 0{,}08...8{,}8$ A, $L_b = 0{,}04...1$ mH, $C_b = const = 0{,}225$ F.

Dependency graphs were constructed according to the results of experiments (fig. 7, 8 and 9).



a) b)

Fig. 7. The energy performance of the motors in acceleration and deceleration mode: a – energy capacitor in $\Delta I_{ces} = const$; b – stored energy of locomotive moving masses in $\Delta I_{ces} = const$

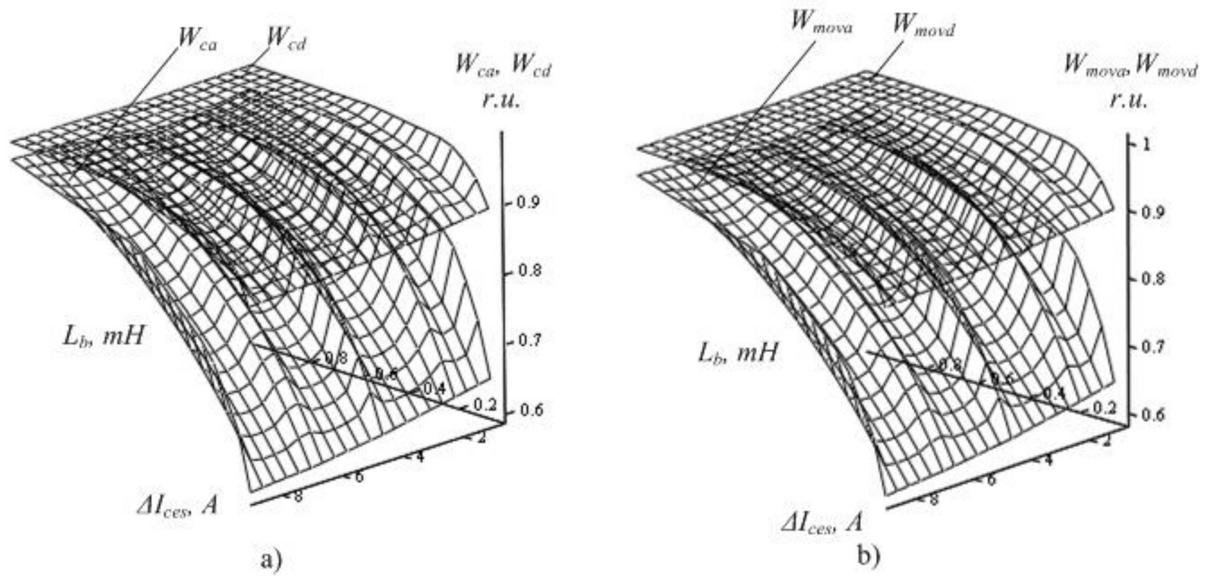


a) b)

Fig. 8. The energy performance of the motors in acceleration and deceleration mode: a – energy capacitor in $L_b = const$; b – stored energy of locomotive moving masses in $L_b = const$

Conclusions.

1. The model for research energy processes in the system controlled storage capacitor – DC motor was developed, which allows acceleration mode, sustainable movement and deceleration of locomotive.
2. In result of a number experiments with the variation of system parameters, were researched energy performance by changing the buffer values of inductance, capacitance and current pulsations amplitude, by graphic dependencies were decided:



a) b)

Fig. 9. The energy performance of the motors in acceleration and deceleration mode: a – energy capacitor in $C_b = const$; b – stored energy of locomotive moving masses in $C_b = const$

– substantial losses of the armature strongly dependent on the buffer inductance L_b, namely, reduced with its growth, at $L_b > 3L_a$ change of energy loss is not observed, that is, just select the buffer inductance value $L_b \approx 3L_a$;

– in the considered range of parameters dependence accumulated (mechanical) / devoted (electrical) energy from the buffer inductance L_b is 10...25%, while the change of capacitance in 5 times the calculated gives increase 2...4%, that testifies inexpediency of capacity increase relatively to calculated;

– a substantial change of amplitude current pulsations ΔI_{ces} and capacitance of capacitor energy storage C cause a small change of energy performance 1...3%.

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