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Simulation of electromagnetic drives, taking into consideration external mechanical exposures

Applied Electromagnetics and Circuit Theory

While in service inventory of the car, in particular, electromagnetic drives are exposed to intensive action of exterior mechanical factors (shocks, vibrations, linear accelerations). Severe constraints of maintenance render the considerable effect on serviceability and reliability of operation of electromagnetic drives and demand the estimation of serviceability and optimization of a construction at a design stage. Use of the experimental methods for this purpose considerably increments terms and costs of design operations.

The offered approach to a solution of this problem is the preliminary simulation modeling of the devices being developed for which mathematical models and the matching software should be created.

The structure of the generalized mathematical model of mechatronic electromechanical system is shown in figure 1.

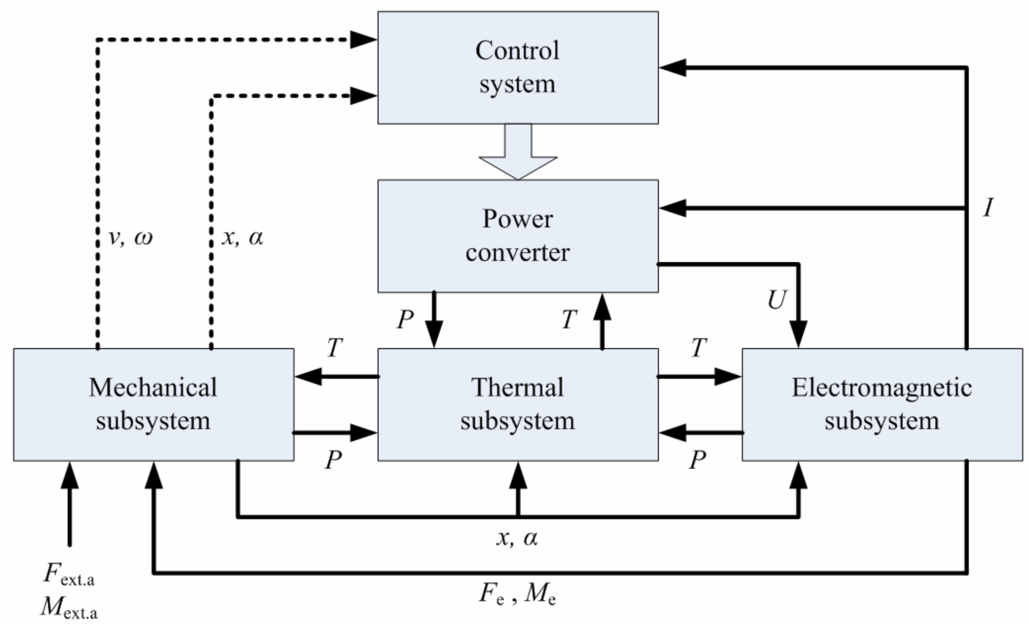

Fig.1. Structure of the generalized mathematical model of mechatronic electromechanical system

In a mechanical subsystem skew fields, turning devices, force factors (interior and exterior), character of driving, etc., in electromagnetic and thermal ones - a configuration of the calculated area of a temporary magnet, parameters of materials are featured. Each subsystem perceives both characteristic, and the cross revolting actions related to additional physical phenomena, occurring in it. For example, in a mechanical model there can be a friction dependent or independent on temperature. In an electromagnetic model occurrence of the induced eddy currents changing force performance alongside with signals of control is possible. The effect of exterior mechanical factors is considered by introduction in model of the oscillator of revolting actions.

At shaping mathematical model of mechanical processes the considered device is represented in the form of a system of the rigid bodies related by means of kinematics and forces elements. In a basis of the model of mechanical processes equations of motion which generally can be presented as follows are included:

$$\begin{aligned} &M(q,t)\ddot{q} + k(q,\dot{q},t) = Q(q,\dot{q},t) + G^T(q)\lambda, \\ &h(q,p) = 0, \end{aligned} \qquad (1)$$

where *q* - the basic coordinates of plant, *p* - auxiliary coordinates (local coordinates in the slited rotating joints); *M* - a matrix of masses, *k, Q* - columns of inertial forces and the generalized forces; λ - the Lagrangian multiplicities matching forces of responses in slited rotating joints; $h(q,p)=0$ - the algebraic equations of connections or requirements of closure of the slited rotating joints. Matrix *G* is a matrix of Jacobi of the equations of connections after elimination of auxiliary coordinates from them.

The model is realized with use of a program complex «Universal Mechanism. Version 3.0 Demo» © [1]. The program complex synthesizes equations of motion in the symbolical shape. As practice shows, such an approach combined with application of procedures of factoring out and substitutions, is more effective, from the point of view of a drop of the number of arithmetical operations.

At shaping and solving the equations of connections (1) at representating of some of arbitrary initial values basic q_0 and auxiliary coordinates p_0, they do not satisfy to the equations of the connections (1), being the requirements for closure of the slited rotating joints. It is required to define corrections Δq, Δp so that new values of coordinates should satisfy to the equations of connections, that is

$$h(q_0 + \Delta q,\, p_0 + \Delta p) = 0. \qquad (2)$$

In the program the iterative method of Newton-Rafsons solution of a system of the non-linear equations (2) is realized. On each iteration a non-linear system is linearized, and the system is a subject to a solution

$H_q(q^k, p^k)\Delta q^{k+1} + H_p(q^k, p^k)\Delta p^{k+1} = -h(q^k, p^k)$,

$q^{k+1} = q^k + \Delta q^{k+1}$, $p^{k+1} = p^k + \Delta p^{k+1}$, k=0,1...

$q^0 = q_0$, $p^0 = p_0$.

Here H_q, H_p are matrixes of Jacobi of function h. Iteration with number k is performed in the following sequence. For each slited rotating joint the linearized equation of connections is under construction

$$H_{q,i}(q^k, p^k{}_i)\Delta q^{k+1} + H_{p,i}(q^k, p^k{}_i)\Delta p^{k+1}{}_i = -h(q^k, p^k{}_i), \quad (3)$$

into which only a part of auxiliaries enters, namely - local turning coordinates. By means of a method Gauss auxiliaries $\Delta p^{k+1}{}_i$ are expelled from the equation (3) and the matrix equation (3) is parted in two:

$$\Delta p^{k+1}{}_i = P_i \Delta q^{k+1} + \delta p^k{}_i, \quad (4)$$

$$G_i^k \Delta q^{k+1} = -g_i^k. \quad (5)$$

Further the equations (5) are merged in one set of equations

$$G^k \Delta q^{k+1} = -g^k, \quad (6)$$

which solution is implemented by a method of Gauss with searching a pivot in a line. Thus gains of the coordinates matching pivots rely zero, and the remaining coordinates obtain gains according to a solution of the equation (6). Entries Δq^{k+1} are substituted in formulas (4), and gains of auxiliaries' $\Delta p^{k+1}{}_i$ are defined. If the norm of the gained gains of coordinates is less than the given exactitude, process of a solution comes to an end, following iteration otherwise is fulfilled.

At model operation of electromagnetic processes the considered device is represented in the form of a system of magnetic linkages circuits which relative position from each other can vary. Processes in such system are featured by a system of the differential equations concerning magnetic linkages of the circuits made up as a Faraday law of induction, and a system of the algebraic equations linking the currents and magnetic linkages of these circuits. For a solution of the formulated problem the computational scheme cited in [2] is used. Considering the complicated configuration of the devices of a magnetic system of a drive for defining magnetic linkages of windings on their currents methods of a field theory have been used. Calculation by methods of a field theory for electromagnetic processes is performed in an axially symmetric statement of problem. At calculation of a magnetic field program complex Femm 3.4 [3] in which the problem of calculation is stated concerning a vector magnetic potential is used. Fundamental relations of the model can be presented by a following set of equations

$$\begin{cases} rot\vec{H} = \vec{\delta} \\ rot\vec{E} = -\dfrac{\partial \vec{B}}{\partial t} \\ \vec{B} = \mu \cdot \vec{H} \\ div\vec{B} = 0 \\ div\vec{\delta} = 0 \\ \vec{\delta} = \gamma \cdot \vec{E} \end{cases} \tag{7}$$

with matching boundary and starting conditions. In the set of equations (7) the following labels are used: $\vec{B}$ and $\vec{H}$ – magnetic displacement vectors and a magnetic intensity accordingly; $\vec{E}$ – an electric-field vector; μ – the relative magnetic permeability of a material of a massive section; γ – a direct-current conductivity of a material of a massive section; $\vec{\delta}$ – a vector of a current density.

Calculation of the axially symmetric magnetic field featured by these equations, is reduced to a solution of a boundary value problem as

$$\frac{1}{r}\frac{\partial}{\partial r}\left(\nu\frac{\partial A}{\partial r}\right) + \frac{\partial}{\partial z}\left(\nu\frac{\partial A}{\partial z}\right) = -\delta \tag{8}$$

where A – a vector magnetic potential;

$\nu = \dfrac{1}{\mu}$ – a magnetizability of a medium;

δ – a vector of a current density, with boundary conditions of an aspect $A = 0$ or $\dfrac{\partial A}{\partial n} = 0$.

The control system according to the data gained from other subsystems (velocity *v* and transition *x* armatures, currents of windings *I*, fig.1) determines the moments of switching of key devices of the power converter. Voltage from its exit (*U*) is transmitted to an electromagnetic subsystem. There from a mechanical subsystem the information on transition of the mobile members arrives. Electromagnetic force (F_e), currents of windings and a selected thermal rating (*P*) are transmitted to a mechanical subsystem, a control system and the power converter, and a thermal subsystem in accordance with the block diagram cited in fig.1.

Calculation of the processes in the power converter is fulfilled by methods of an electrical circuit analysis. Considering, that the purpose of calculations is the analysis of electromagnetic and electromechanical processes in a drive, power semiconductor devices are replaced by the key devices having major resistance in an off-state and small resistance - in on unclosed state, instantly switching from one state to another.

In a thermal subsystem by the known thermal ratings and relative positions of the construction members allocation of temperature in the given area and devices of the power converter is calculated. Outcomes of calculation are transmitted to subsystems in accordance with the block diagram cited in fig.1. The module of thermal calculations uses program complex Mirage 1.0 [4]. Fundamental relations of the model can be presented by a heat conduction equation. Calculation of axially symmetric temperature pattern is reduced to a solution of a boundary value problem as

$$\lambda_r \frac{\partial^2 T}{\partial r^2} + \lambda_r \frac{1}{r}\frac{\partial T}{\partial r} + \lambda_z \frac{\partial^2 T}{\partial z^2} = -q \quad (9)$$

with matching boundary and starting conditions.

Here: λ_r and λ_z – thermal conductivities of a medium in directions of axes of coordinates; q – an apparent density of radiants of heat; $T = f(r, z)$ – required function of temperature allocation; γ – a direct-current conductivity of a material of a large section; $\vec{\delta}$ – a vector of a current density.

For exposition of a procedure of model operation it is expedient to consider an example of a transient analysis in a magnetic system of a drive of the valve gear of the internal combustion engine with two coils (fig. 2). The drive ensuring the controlled phases of gas distribution is employed to, improve the fuel efficiency, to have low emission of harmful substances, and diminish the size of the gasoline engine at simultaneous simplification of the construction and its reduction in price. The electromagnetic system of a valve gas distribution controlled from the computer is capable to realize adaptive installation of phases of valve allocation irrespective of the bent shaft standing.

The demanded dynamics of operation of an electromagnetic drive can be reached by pulse forming voltage on its windings. The parameters of impulses are determined either on the basis of outcomes of model operation of a drive (the open control systems), or by means of the special control algorithms using the information from sensors of a winding current, a velocity and transition. In both cases the microprocessor device which shapes the pilot signals ensuring the given dynamics of switching is used. Control of the drive in the given design was carried out by pulse forming the given duration.

By means of the developed software there has been performed a simulation modeling of operation of an electromagnetic drive of the valve gear of the internal combustion engine at its switching from position "open" to position "closed" and processes in an electromagnetic drive at various kinds of exterior mechanical actions (vibration, shocks, etc.) have been analyzed. As an instance the outcomes of calculations of the processes are introduced at switching the valve without action of exterior factors and at presence of vibration of the foundation (the direction coincides with a driving direction of an armature, frequency of 500 Hz, amplitude of sine vibration of 0,15 mm).

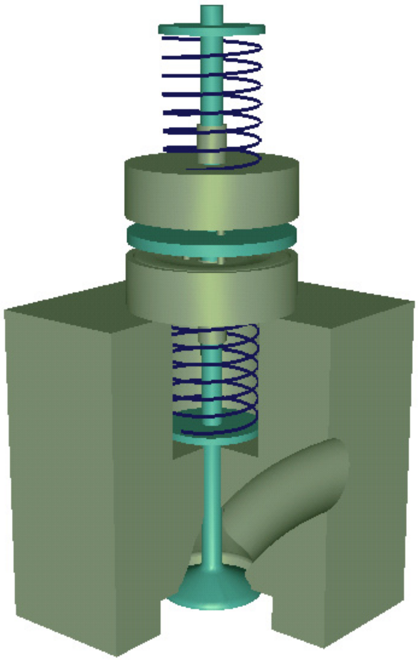

Fig.2. Electromagnetic drive of the valve gear of the internal combustion engine

Below the results of imitation of the drive operation are cited at switching the valve (fig.3 - without action of exterior factors, fig.4 - at presence of vibration of the foundation):

fig.3a, fig.4a - voltage pulses on upper winding U_1;

fig.3b, fig.4b - voltage pulses on upper U_1 and lower U_2 windings;

fig.3c, fig.4c - a current in upper winding I_1;

fig.3d, fig.4d - a current in upper I_1 and lower I_2 windings;

fig.3e, fig.4e - a modification of a tractive power at transition of an armature to position « the valve is closed »;

fig.3f, fig.4f - a modification of a tractive power at transition of an armature from position «the valve is closed» to position «the valve is open»;

fig.3g, fig.4g - transition of an armature to position «the valve is closed»;

fig.3h, fig.4h - transition of an armature from position «the valve is closed» to position «the valve is open»;

fig.3i, fig.4i - a modification of a velocity of an armature at transition of an armature to position «the valve is closed»;

fig.3j, fig.4j - a modification of a velocity of an armature at transition of an armature from position «the valve is closed» to position «the valve is open».

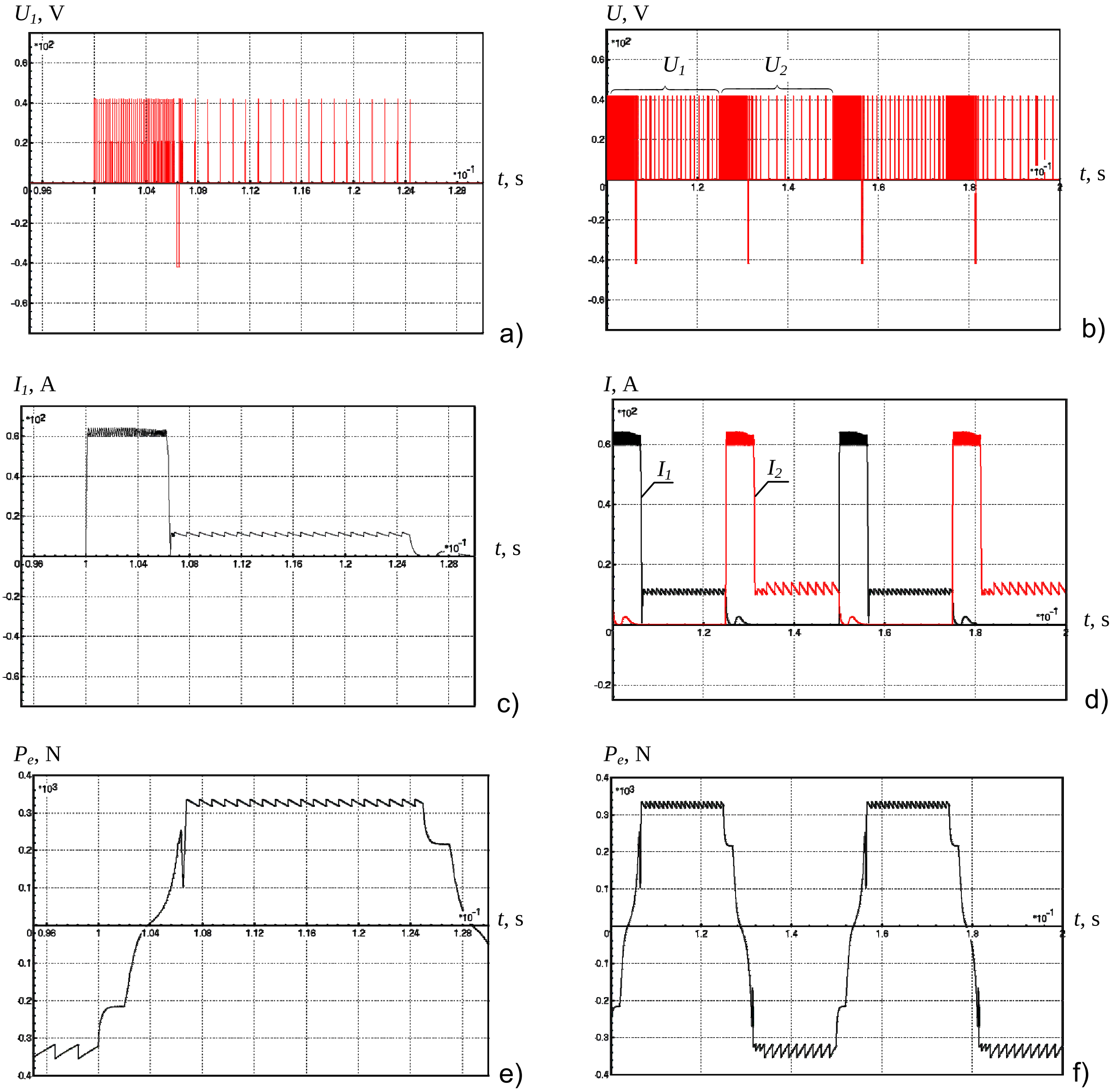

Fig.3 Dynamic characteristics without action of exterior factors

(See also following page)

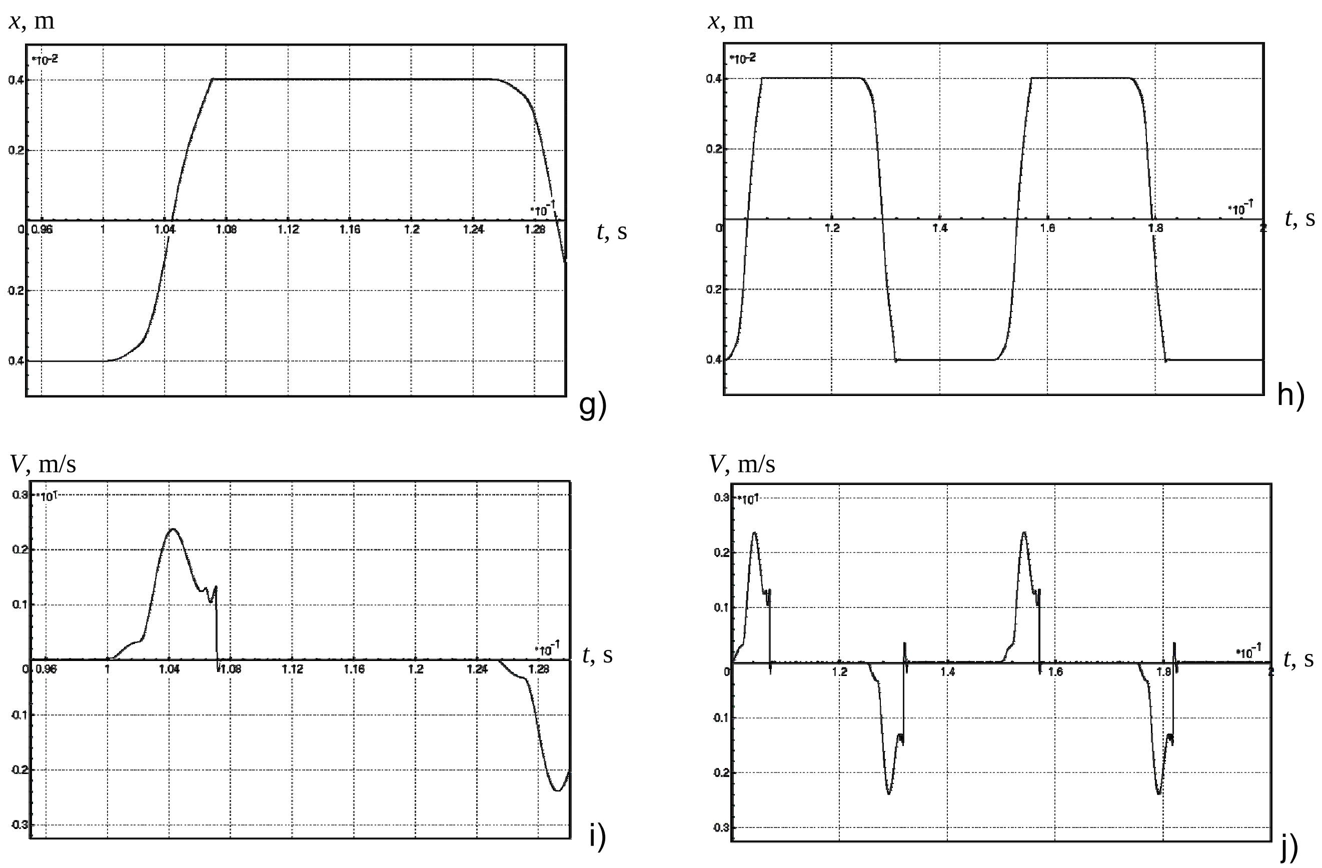

Fig.3 Termination

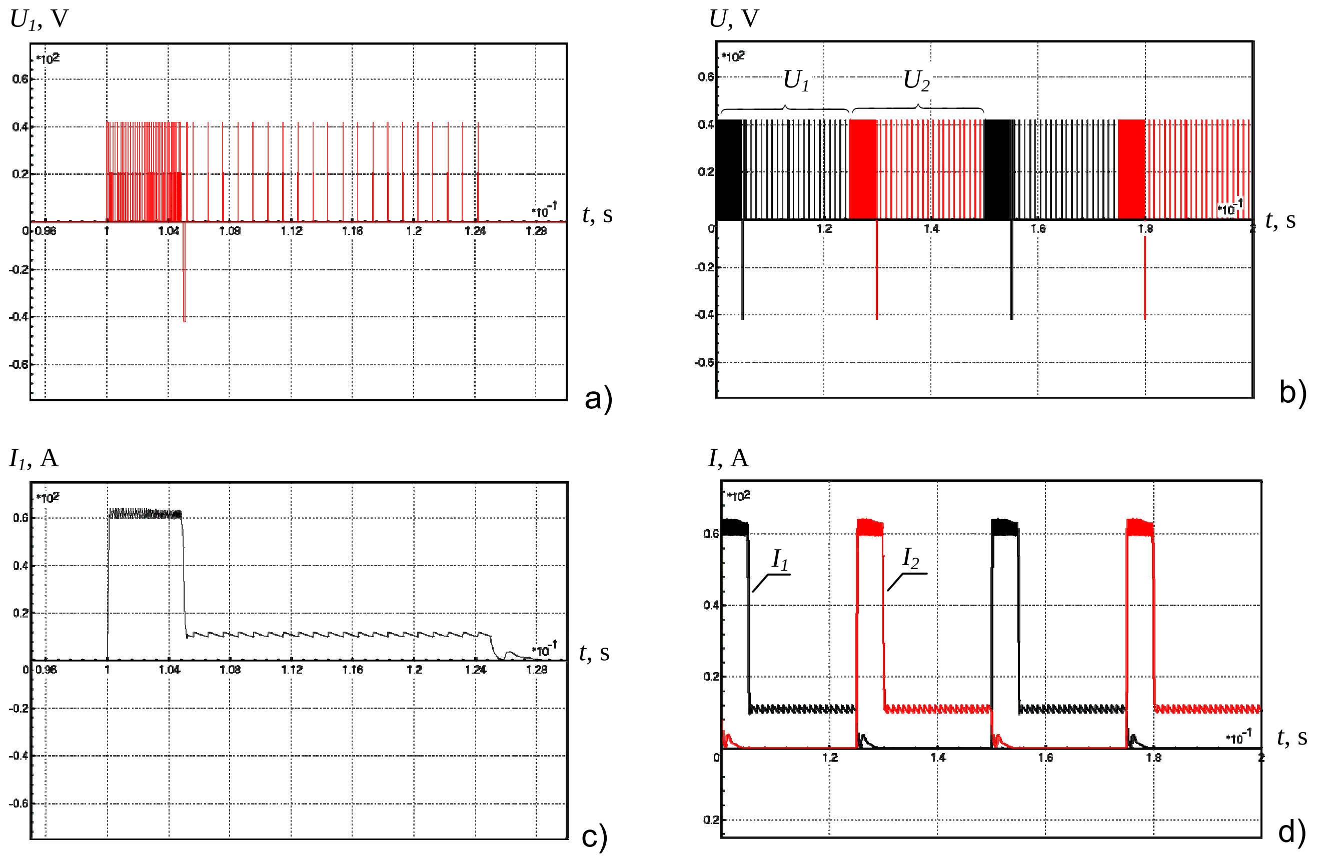

Fig.4 Dynamic characteristics in view of exterior actions
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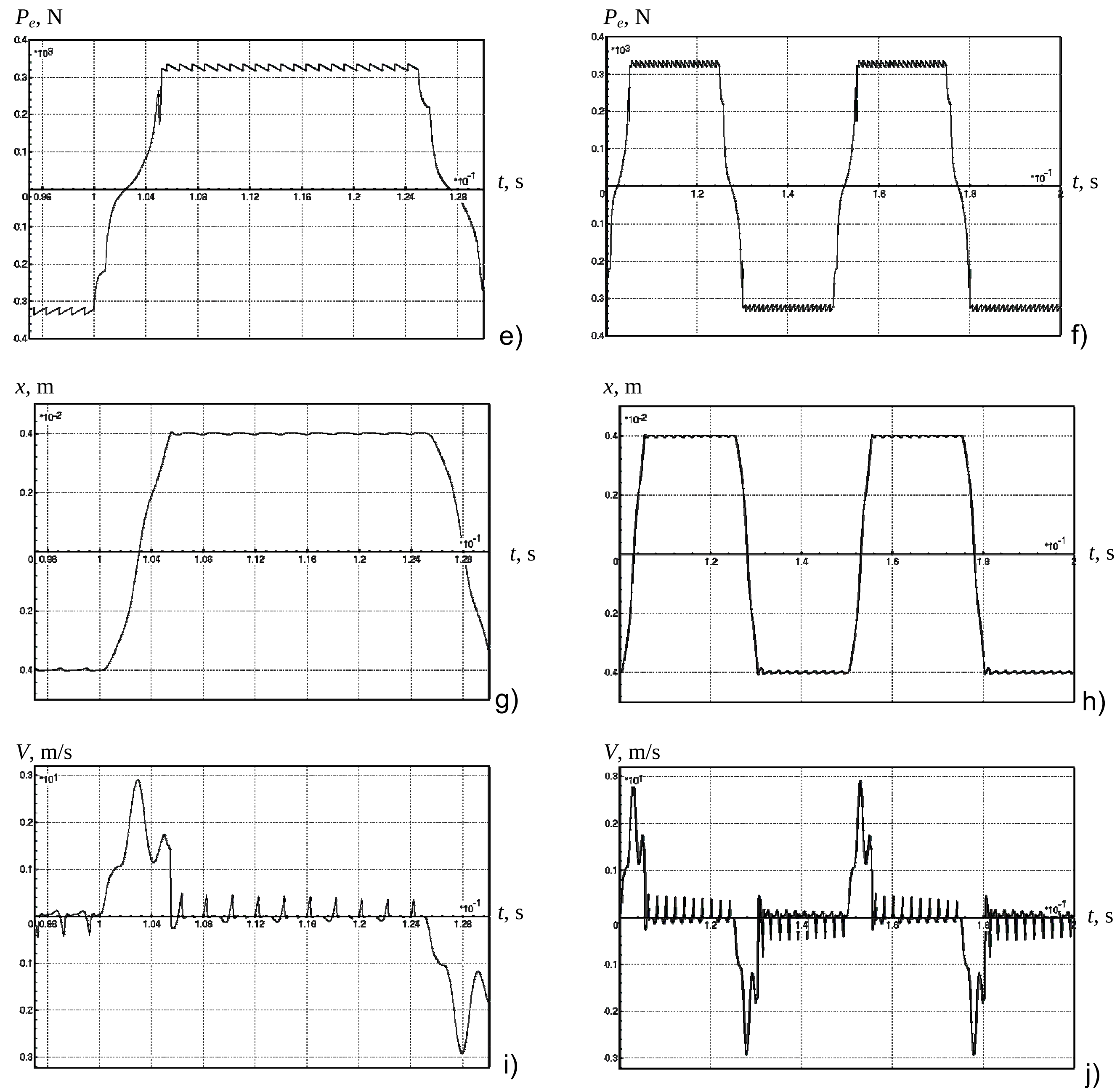

Fig.4 Termination

The gained outcomes have allowed leading a multicriteria optimization of a construction for magnification of its fast operation and a raise of its reliability in the hardest service conditions. Application of a complex mathematical model enables to consider the effect of mechanical actions on a magnetic system at a design stage of an electromagnetic drive.

References:

[1] Demonstration Version UM 3.0 for Windows NT/2000/XP,
http: // umlab.ru/download/um30demo.exe (37 Mb)
[2] Kolpahchyan P.G. Adaptive control of Asynchronous Tractive Drive of Main Line Electric Locomotives. – Rostov-on-Don: Publishing House of Journal «Higher School Proceedings. North-Caucasian Region», 2006. - 131 pp.
[3] Program Complex FEMM 4.0
http: // femm.foster-miller.net/Archives/bin/femm401bin.exe (1.4 Mb)
[4] Program Complex Mirage 1.0
http: // femm.foster-miller.net/Archives/bin/mirage10bin.exe (0.943 Mb)

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