UDC 62-50

SYNTHESIS of the CONTROL SYSTEM by ELECTRIC DRIVES

T.T.Omorov, B.O.Dzholdoshev, R.N.Kurmanalieva
(Institute of automatics NAS KR, KSUCTA)

THE SUMMARY

1. Statement of a task of synthesis. In practice of automation of productions the significant place is occupied with questions of perfection of the control systems having as power elements electric drives [1, 2]. Further the task of management by the system consisting of two electric drives and functioning in structure of a technological complex of processing and rewind of lengthy materials (fig. 1) is considered.

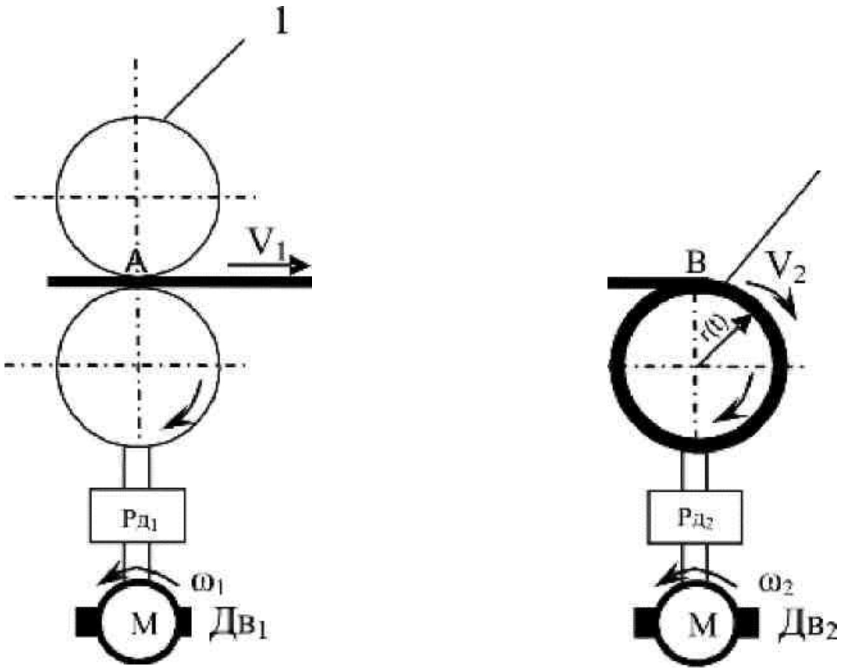


Fig. 1. The kinematic scheme (plan) of system.

The Material (the tape, a wire, etc.) passes through are shaky 1 and is reeled up on the reception coil 2 which rotates the second engine (□□2). Thus current value of diameter of the coil r(t) increases, that leads to increase of the moment of inertia (□□$_2$). For maintenance of desirable quality of technological process in such systems there is a necessity of the interconnected management of electric drives, and also maintenance of demanded speed and accuracy of regulation of the basic variables. One of the important problems of management consists in maintenance of key parameters of process under the certain law, to which their number it is possible to carry linear speeds of movement material $V_1(t)$ and $V_2(t)$ on outputs corresponding section, size of effort in a strip and other parameters. In particular, it is possible to adjust speed $V_1(t)$ and the ratio between sizes $V_1(t)$ and $V_2(t)$.

In the beginning we shall construct mathematical model of considered object of management. The equations of the first **fl**$_{B1}$ and second **fl**$_{B2}$ engines look like [1]:

$$J_1 cn_1(t)=M_1(t)-M_{c1}(t),$$
$$J_2 a>_2(t)=M_2(t)-M_2(t), \quad (1)$$

Where $\mathbf{a}_1$ **H** $\mathbf{a}_2$ - angular speeds accordingly the first and second engines; J_1, J_2 - the moments of inertia led shaft of corresponding engines; $M_1, M_2 M_{c1} M_{c2}$ - the moments of rotation and resistance accordingly:

$$M_1(t)=77_1 u_1(t), \qquad M_2(t)=r,_2 u_2(t), \quad (2)$$
$$M_{c1}(t) = \mathbf{A}\hat{}(t), \qquad M_{c2}(t) = (3_2 0)_2(t),$$

And $u_1(t)$, $u_2(t)$, - pressure on an entrance of amplifiers of capacity which are operating influences of the first and second engines; Q1,Q1,P1,f_2 - Constant factors.

Dynamics of the reception coil is defined by the equations [1]

$$r(t) = c_1 V_2(t), \quad (3)$$

$$\&_2(t) = c_2 r^3(t) r(t),$$

Where c_1 and c_2- constant factors. If to assume, that linear speed $v_2(t)$ is supported at level v_2^*, i.e. $v_2(t)=v_2^*$,=const decisions of these equations can be received in the obvious form [2]:

$$r(t) = jr^2(t_0) + c_3 t, \quad (5)$$

$$J_2(t) = J_2(t_0) + c_4[r^4(t)-r^4(t_0)], \quad (6)$$

Where $\mathbf{c}_3$ and c_4- constant factors.

Speeds of a strip $V_1(t)$ also $V_2(t)$ are defined as:

$$V_1(t) = k_1 a>_1(t), \quad (7)$$

$$V_2(t) = k_2 o>_2(t) r(t), \quad (8)$$

Where k_1, k_2- the constant factors considering transfer numbers of reducers; r(t) -radius of the reception coil during the moment of time t.

To one of the parameters of quality of technological process serves it is nonviscous

$$A(t) = '0-(t), \quad (9)$$

Where •0 - distance centre to centre section (points And and); .(t)-actual length of a material between these centers. During management it is necessary to aspire to that zero value A(t)was supported.

It is easy to show, that nonviscous $X(t)$ is described by the equation

$$\hat{}t) = V_1(t)-V_2(t). \quad (10)$$

Now the equations (1) we shall write down concerning linear speeds $V_1(t)$ and also V2(t). For this purpose differentiate ratio (7) and (8):

$$\dot{V}_1(t) = k_1\dot{\omega}_1(t),$$
$$\dot{V}_2(t) = k_2\omega_2(t)\dot{r}(t) + k_2 r(t)\dot{\omega}_2(t). \quad (11)$$

As a result of simple transformations in view of (1), (3) and (7) equations (11) it is possible to present in the form of

$$\dot{V}_1(t) = a_1V_1(t) + b_1u_1(t),$$
$$\dot{V}_2(t) = a_2(t)V_2(t) + a_3V_2^2 + b_2u_2(t), \quad (12)$$

Where

$$a_1 = - \sim, \quad a_2 = - \sim, \quad a_3 = a_3(r) = \sim, \quad (13)$$
$$b_1 = J_1, \quad b_2 = b_2(r) = J_2 (\sim .$$

Thus, uniting the equations (3), (10), (12) it is received following mathematical model of operated object:

$$\dot{V}_1(t) = a_1V_1(t) + b_1u_1(t),$$
$$\dot{V}_2(t) = a_2V_2(t) + a_3V_2^2(t) + b_2u_2(t), \quad X(t) = V_1(t) - V_2(t), \quad r(t) = a_4V_2(t),$$

Where $a_4 = a_4(r) = r (t$. Apparently from the equations (14) the investigated object is nonlinear non-stationary dynamic system.

Operated variables of system are

$$y_1(t) = V_1(t), \qquad y_2(t) = A(t). \quad (15)$$

Errors of management are determined by ratio

$$e_1(t) = V_1(t) - g_1 = V_1(t) - V_1^*,$$
$$e_2(t) = l(t) - g_2 = l(t) - l^*, \quad (16)$$

Where g_1, g_2 - desirable values of operated sizes

$$g_1 = V_1^* = const,$$
$$g_2 = l^* = 0. \quad (17)$$

Quality of management is defined by restrictions on transients by errors of management:

$$|e_1(t)| \le \delta_1(t),$$
$$|e_2(t)| \le \delta_2(t), \qquad t \in [t_0, t_k], \quad (18)$$

Where $\delta_1(t)$, $\delta_2(t)$ - the functions of determining borders of admissible areas $E_1(t)$ and $E_2(t)$:

$6_1(t)=6_1 0e^{\alpha}$, $6_2(t) = 60e-$, $t_0=0$, $t_k=7ce_K$,
$6_1^0=0{,}3$, **6**$0=0{,}1$, **a** $= -0{,}95$.

It is necessary to note, that observance of conditions (18) provides time of regulation of system T^ 3,5 sec, T_2<3,5sec.

Now the task of synthesis of a control system of object which dynamics is described by the equations (14), is formulated as follows. To determine the law of the management $u(t) = u_1(t), u_2(t)$**F**providing guaranteed performance of requirements to quality of management (18).

2. Structural synthesis of a regulator. For the decision of the formulated task of management we shall use a technique of structural synthesis of the regulator, stated in chapter 2. For this purpose dynamics of object (14) we shall write down in deviations:

$$x_2(t) = V_2(t)-V_2^*,$$
$$x_3(t) = \mathbf{X}, \qquad (19)$$
$$)_1(t)=u_1(t)-u_1^*(t),$$
$$u_2(t) = u_2(t)-u_2^*(t),$$

Where $u_1^*(t)$, $u_2^*(t)$ - components of a nominal vector of management $u^*(t)$*are* defined from ratio (14):

$$u_1^*(t)=-a\mathbf{v;},$$

In view of (19) and (20) equations of object (14) have a form

$$x\&_1(t) = a_1x_1(t) + b_1u_1(t),$$
$$x\&_2(t) = a\sim_2(t)x_2(t) + a_3x_2^2(t) + b_2u_2(t), \qquad (21)$$
$$x\&_3(t) = x_1(t)-x_2(t)$$

Where $a_2=a_2+2a_3V_2^*$.

Instead of last equation of system (14) its decision in the form of (5) further is used.

We shall enter a vector of the displaced variables of a condition $x = [x_1,x_2,x_3]^T$. Then in view of (15) vector of an exit of object

$$y(t) = Cx(t), \qquad (22)$$

Where a matrix

$$C = [0\ \ 0\,0\,0$$. The

Derivative

$$y\&(t)=Cx\&(t). \qquad (23)$$

Component-wise record of this ratio looks like

$$\dot{y}_1(t) = a_1 x_1(t) + b_1 u_1(t),$$
$$\dot{y}_2(t) = x_1 - x_2 . \qquad (24)$$

According to a technique of structural synthesis of the regulator, stated in [4], in the beginning we shall determine structure of reference model for a vector of a an error of management $e = [e_1, e_2]^T = [y_1, y_2]^T$. the Analysis of ratio (24) shows, that the second equation does not include any operating influence. Therefore structure of reference model we shall set in the form of

$$e(t) = Me(t) + \tilde{e}(t), \qquad (25)$$

Where the vector function $e(t) = [\,0, e_2(t)\,]$. thus function $e_2(t)$ should satisfy to a following condition:

$$|e_2(t)| \le e_2^*(t), \qquad (26)$$

Where $e^*(t)$ - positive continuously differentiated monotonously decreasing function of time which sets accuracy of performance of a meeting functional ratio. Let $e_2^*(t) = e_{2\,0}^* e^{at}$.
Component-wise record (25) has a form:

$$\dot{e}_1 = m_{11} e_1 + m_{12} e_2,$$
$$\dot{e}_2 = m_{21} e_1 + m_{22} e_2 + e_2(t). \qquad (\quad)$$

The Vector-parameter of reference model $p = [p_1, p_2, p_3, p_4] = [m_{11}, m_{12}, m_{21}, m_{22}]$ it is necessary for determining so that to provide conditions of admissible quality of management (18).

Using results of statements 1-3 [4] it is received, that errors of management $e_1(t) \in E_1(t)$ and $e_2(t) \in E_2(t)$ if inequalities are carried out

$$p_2 \Delta_2^0 \le (a - p_1)\Delta_1^0,$$
$$p_3 \Delta_1^0 + e_{2\,0}^* \le (a - p_4)\Delta_2^0. \qquad (28)$$

The simple analysis of system of inequalities (28) shows, that at $p_2 = 0$, $p_3 = 0$ That the error is enough performance of following conditions:

$$p_1 \le a, \qquad p_4 \le a - \frac{e_{2\,0}^*}{\Delta_2^0}. \qquad (29)$$

The First equation of synthesis has a form

$$a_1 x_1(t) + b_1 u_1(t) = p_1 e_1(t). \qquad (30)$$

The Second equation of synthesis it is received from a condition of maintenance of a ratio (26). On the basis of a demanded functional ratio $\dot{e}_2(t) = \dot{y}_2(t)$ we define function

$$e_2(t) = x_1 - x_2 - p_4 x_3, \qquad (31)$$

Which derivative has a form

$$\dot{e}_2(t) = \dot{x}_1 - \dot{x}_2 - p_4 \dot{x}_3 . \qquad (32)$$

dynamics $e_2(t)$ submitted to the law We Shall demand, that

$$\dot{e}_2 = g_2 e_2(t), \qquad (33)$$

Where y_2 - the parameter chosen from a condition of maintenance of a ratio (26). On the basis of the statement 2.2 for definition [2] it is had a following condition:

$$7_2 e_2^*(t) < e_2^*(t). \quad (34)$$

From here in view of that $e^*_2(t) = e_2 e^{at}$ the parameter y_2 should satisfy to a condition:

$$(35)$$

Further on the basis of a ratio (33) in view of (31) and (32) it is received the second equation of synthesis:

$$(a_1 - p_4\ _4)x_1 \quad bu \quad a_2 x_2\ x_2 - a_3 x\ 2_2 + b_2 u_2 = y_2 (x_1 - x_2 - p_4 x_3). \quad (36)$$

Deciding the equations (30) and (36) the required law of management is received

$$u_1(t) = k_1 x_1(t), \quad (37)$$

$u_2(t) = k_2 x1(t) + k_3 x_2(t) + k_4 x_3 + k_5 x_2$, Where factors of a regulator

$$k_1 = (p_1 - a_1), \quad k = \frac{p_1 - p_4 - y_2 = (p_1 - a1)}{b_2} \quad ,k_3 \quad \frac{}{b_2}\ _2, \quad k_4 = \frac{_2 p_4}{b_2}, \quad k_5 = -\frac{a_3}{b_2}. \quad p_4 - a_2 + y_2$$

It is necessary to note, that the synthesized regulator concerns to a class of nonlinear systems. Research a question on synthesis a linear operating subsystem is interested of simplification of its technical realization. For this purpose it is possible to use linear model of object of management which can be received from the initial equations (21):

$$x_1(t) = a_1 x_1(t) + b_1 u_1(t),$$

$$x_2(t) = a \sim_2 x_2(t) + b_2 u_2(t), \quad (38)$$

$x_3(t) = x_1(t) - x_2(t)$. The Simple analysis shows, that the law of the management $u(t)$ providing for object (38) conditions guaranteed fulfillment of admissible quality (18) has a following appearance:

$$u(t) = \begin{bmatrix} u_1(t) \\ u_2(t) \end{bmatrix} = \begin{bmatrix} k_{11} & k_{12} & k_{13} \\ k_{21} & k_{22} & k_{23} \end{bmatrix} \begin{bmatrix} x_1(t) \\ x_2(t) \\ x_3(t) \end{bmatrix}, \quad (39)$$

Where

$k_{11} = k_1$, $k_{12} = 0$, $k_{13} = 0$, $k_{21} = k_3$, $k_{22} = k_3$, $k_{23} = k_5$.

3. Computer modelling of a control system. Entering into structure synthesized SAU engines of a direct current (fle1 and £B2) with independent excitation have following values of parameters:

$J_1 = 0{,}02$^.c^2, $J_2(t_0) = 0{,}03$ KZ-C^2 ,

A = 0,01 K2-M^2/C, A = 0,015 K2-M^2/C,

$_m = 0{,}1 K_S.M^2.pad/(B.c^2)$, $_{V2} = 0{,}12 K_S.M^2.pad/(B.c^2)$.

Factors

$\sim_1=0{,}04$, $k_2=0{,}03$, $c_1=0{,}16\times10^{-3}$, $c_3=60{,}5$, $c_4=0{,}5\times10^{-3}$.

The Control system should provide stabilization of following values of operated variables:

$$V_1^* = 3\ \square/\square, \qquad l^* = 0.$$

Thus factors of the equations of object (21) has a form

$$a_1 = -0{,}5c^{-1},\ b_1 = 5{,}0\ pad/(B\times c^2),$$

$$a_2 = --\wedge, \qquad b_2 = 0{,}0036\, r(t),$$

$$a3 = 0{,}16\times10^{-3}, \quad \sim_3 = a_2 + 6a_3, \qquad r(t_0) = 0{,}1M.$$

.

Under the conditions specified above following numerical values of parameters of the synthesized regulator are chosen:

$$p_1 = -1{,}2, \quad p_2 = 0, \quad p_3 = 0, \quad p_4 = -1{,}7, \quad g_2 = -1{,}9.$$

The block diagram of the synthesized control system of the electric drives, focused for computer modelling, it is shown on fig. 2.

Results of computer modelling nonlinear sistems at various entry conditions for a vector of a mismatch □ (t0) =x $_{(t0)}$ with use of program system Matlab/Simulink [5] are resulted on fig. 3 - 4, and control systems with the linear law of management -on fig. 5 - 6. Apparently from schedules of transients both systems provide the set engineering requirements on accuracy and speed. At the same time from the point of view of technical realization application of the linear regulator having the law of management (39) is more expedient.

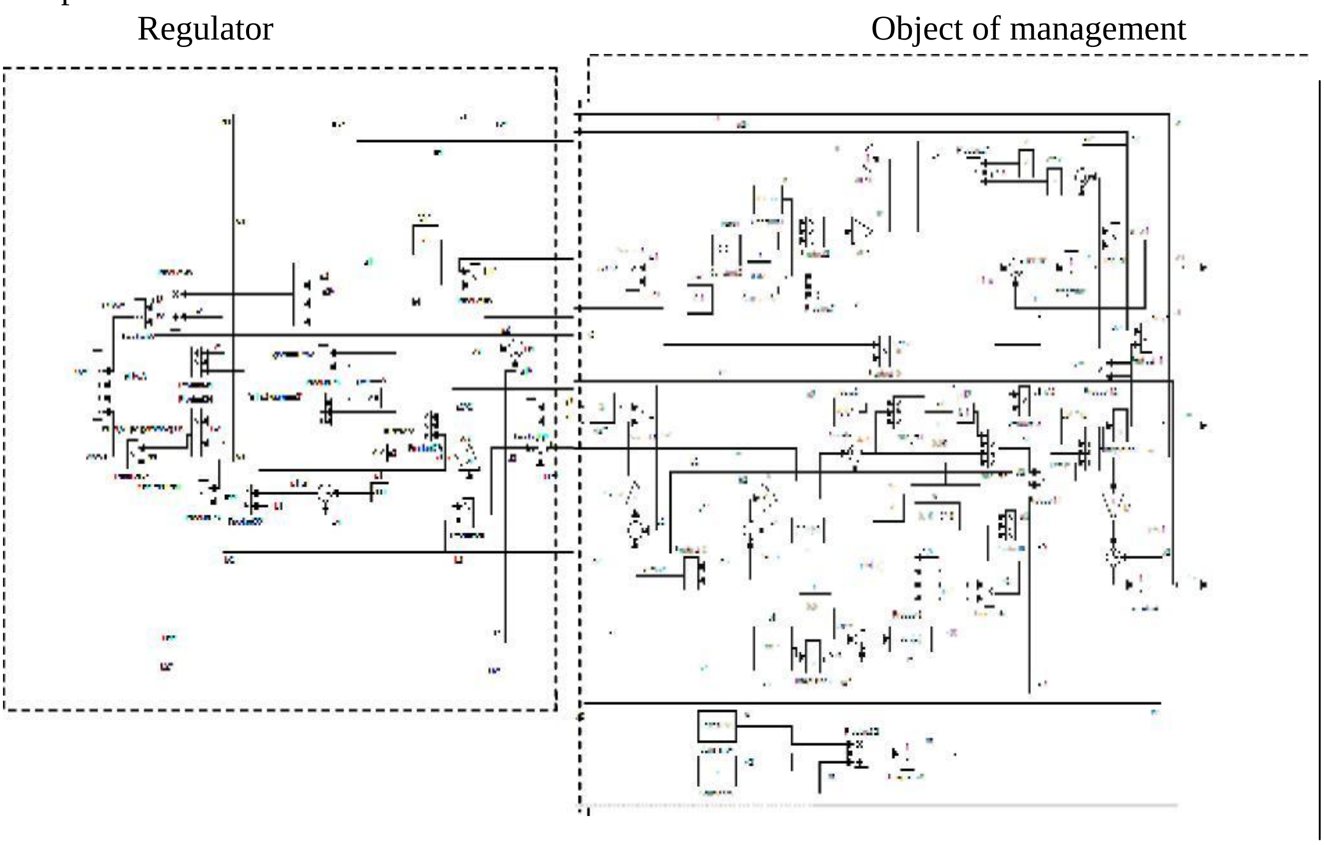


Fig. 2. The Block diagram of modelling on sistems.

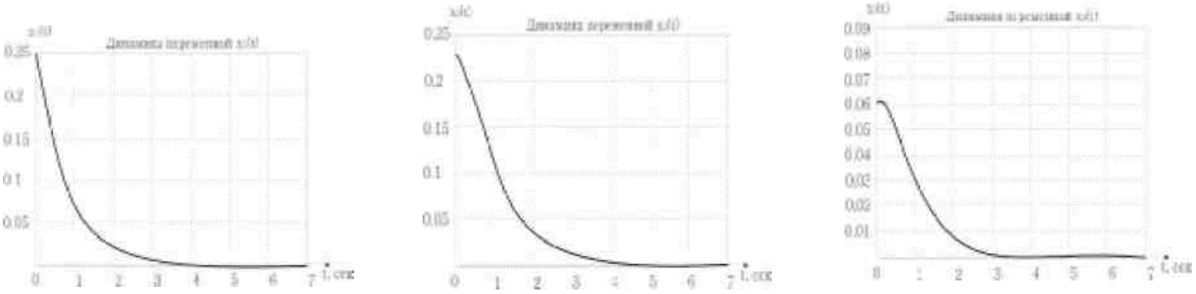
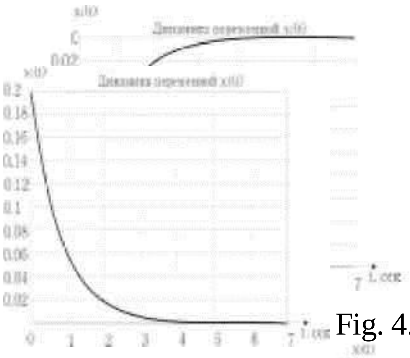
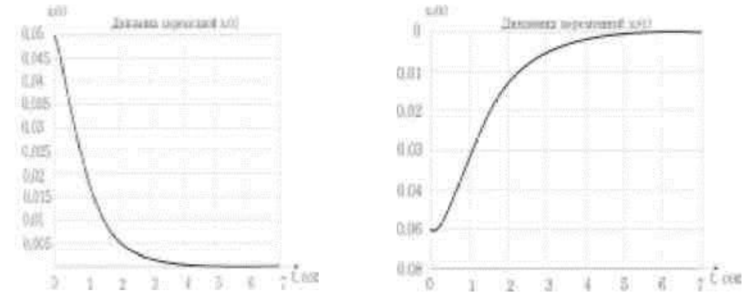


Fig. 3. Transients by mistake with the nonlinear law of management.





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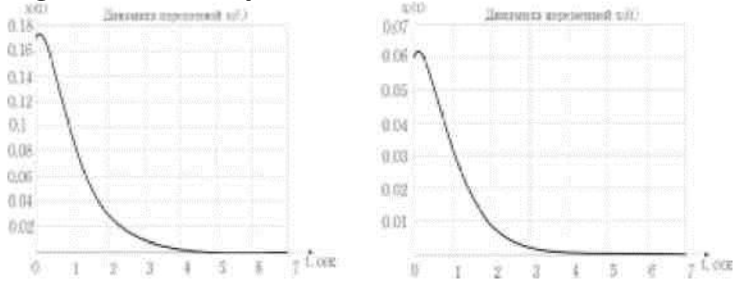

Fig. 5. Mistakes{errors} of regulation with the linear law of management.

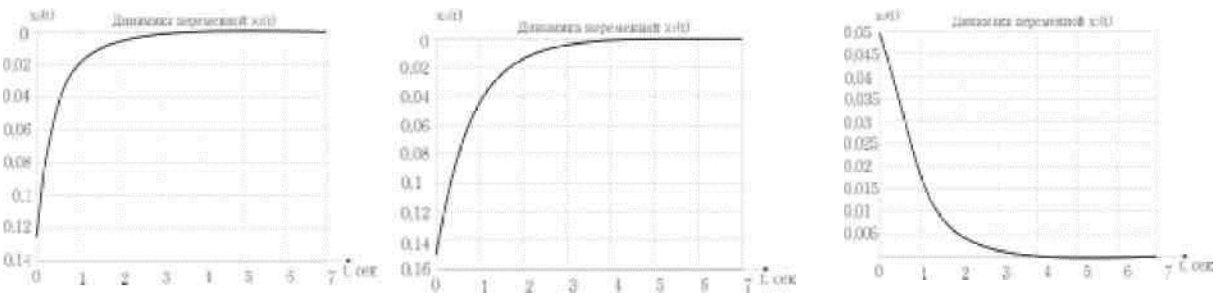

Fig. 6. Errors of regulation with the linear law of management.

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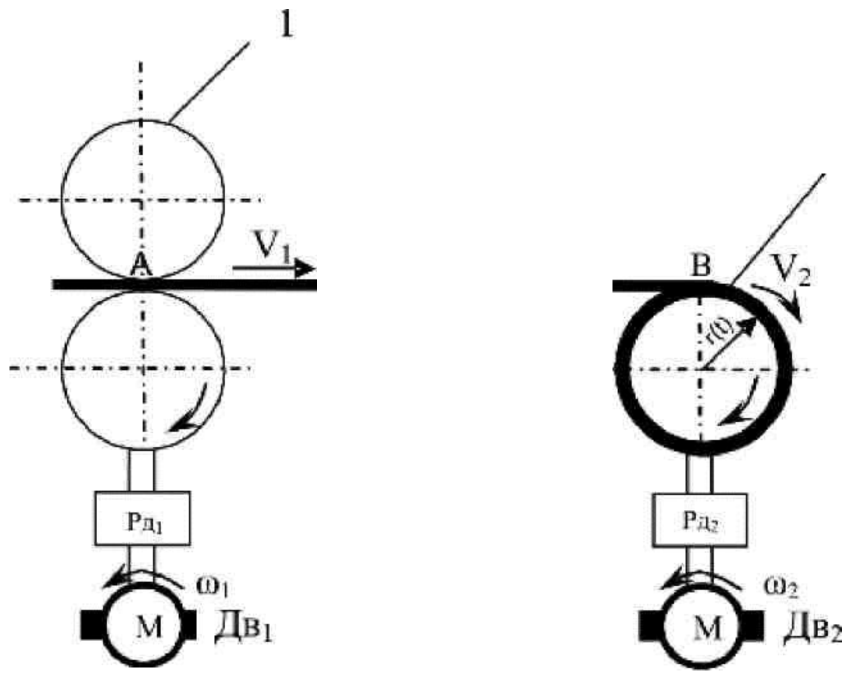

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$$\dot{V}_1 (t) = a_1 V_1 (t) + b_1 u_1 (t),$$
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$$)_1(t) = u_1(t)-u_1^*(t),$$
$$u_2(t) = u_2(t)-u_2^*(t),$$

Where $u_1^*(t)$, $u_2^*(t)$ - components of a nominal vector of management $u^*(t)$*are* defined from ratio (14):

$$u_1^*(t)=-a\mathbf{v};,$$

In view of (19) and (20) equations of object (14) have a form

$$x\&_1(t) = a_1x_1(t) + b_1u_1(t),$$
$$x\&_2(t) = a\sim_2(t)x_2(t) + a_3x_2^2(t) + b_2u_2(t), \quad (21)$$
$$x\&_3(t) = x_1(t)-x_2(t)$$

Where $a_2=a_2+2a_3V_2^*$.

Instead of last equation of system (14) its decision in the form of (5) further is used.

We shall enter a vector of the displaced variables of a condition $x = [x_1,x_2,x_3]^T$. Then in view of (15) vector of an exit of object

$$y(t) = Cx(t), \quad (22)$$

Where a matrix

$$C = [0 \;\; 0\,0\,0$$. The

Derivative

$$y\&(t)=Cx\&(t). \quad (23)$$

Component-wise record of this ratio looks like

$$\dot{y}_1(t) = a_1 x_1(t) + b_1 u_1(t),$$
$$\dot{y}_2(t) = x_1 - x_2 . \qquad (24)$$

According to a technique of structural synthesis of the regulator, stated in [4], in the beginning we shall determine structure of reference model for a vector of a an error of management $e = [e_1, e_2]^T = [y_1, y_2]^T$. the Analysis of ratio (24) shows, that the second equation does not include any operating influence. Therefore structure of reference model we shall set in the form of

$$e(t) = Me(t) + \tilde{e}(t), \qquad (25)$$

Where the vector function $e(t) = [0, e_2(t)]$. thus function $e_2(t)$ should satisfy to a following condition:

$$|e_2(t)| \le e_2^*(t), \qquad (26)$$

Where $e^*(t)$ - positive continuously differentiated monotonously decreasing function of time which sets accuracy of performance of a meeting functional ratio. Let $e_2^*(t) = e_{2\,0}^* e^{at}$.
Component-wise record (25) has a form:

$$e_1 = m_{11}e_1 + m_{12}e_2,$$
$$e_2 = m_{21}e_1 + m_{22}e_2 + e_2(t). \qquad (\quad)$$

The Vector-parameter of reference model $p = [p_1, p_2, p_3, p_4] = [m_{11}, m_{12}, m_{21}, m_{22}]$ it is necessary for determining so that to provide conditions of admissible quality of management (18).

Using results of statements 1-3 [4] it is received, that errors of management $e_1(t) \in E_1(t)$ and $e_2(t) \in E_2(t)$ if inequalities are carried out

$$p_2 \square_2^0 \le (a - p_1)\square_1^0,$$
$$p_3 \square_1^0 + e_{2\,0}^* \le (a - p_4)\square_2^0. \qquad (28)$$

The simple analysis of system of inequalities (28) shows, that at $p_2 = 0$, $p_3 = 0$ That the error is enough performance of following conditions:

$$p_1 \le a, \qquad p_4 \le \frac{a - e_{2\,0}^*}{\square_2^0}. \qquad (29)$$

The First equation of synthesis has a form

$$a_1 x_1(t) + b_1 u_1(t) = p_1 e_1(t). \qquad (30)$$

The Second equation of synthesis it is received from a condition of maintenance of a ratio (26). On the basis of a demanded functional ratio $\dot{e}_2(t) = \dot{y}_2(t)$ we define function

$$e_2(t) = x_1 - x_2 - p_4 x_3, \qquad (31)$$

Which derivative has a form

$$\dot{e}_2(t) = \dot{x}_1 - \dot{x}_2 - p_4 \dot{x}_3. \qquad (32)$$

dynamics [2] submitted to the law e (t) We Shall demand, that

$$\dot{e}_2 = g_2 e_2(t), \qquad (33)$$

Where y_2 - the parameter chosen from a condition of maintenance of a ratio (26). On the basis of the statement 2.2 for definition ^{2} it is had a following condition:

$$7_2 e_2^*(t) < e_2^*(t). \quad (34)$$

From here in view of that $e^*_2(t) = e_2 e^{at}$ the parameter y_2 should satisfy to a condition:

(35)

Further on the basis of a ratio (33) in view of (31) and (32) it is received the second equation of synthesis:

$$(a_1 - p_4\ _4)x_1 \quad bu \quad a_2 x_2\ x_2 - a_3 x 2_2 + b_2 u_2 = y_2 (x_1 - x_2 - p_4 x_3). \quad (36)$$

Deciding the equations (30) and (36) the required law of management is received

$$u_1(t) = k_1 x_1(t), \quad (37)$$

$$u_2(t) = k_2 x1(t) + k_3 x_2(t) + k_4 x_3 + k_5 x_2$$, Where factors of a regulator

$k_1 = (p_1 - a_1)$, $k\ b_2$ $p_1 - p_4 - y_2 =$ $(p_1 - a1)$ $,k_3$ b_2 $_2$, $k_4 = {}_2 p_4$, b_2 $k_5 = - a_3$. b_2 $p_4 - a_2 + y_2$

It is necessary to note, that the synthesized regulator concerns to a class of nonlinear systems. Research a question on synthesis a linear operating subsystem is interested of simplification of its technical realization. For this purpose it is possible to use linear model of object of management which can be received from the initial equations (21):

$$x_1(t) = a_1 x_1(t) + b_1 u_1(t),$$

$$x_2(t) = a \sim_2 x_2(t) + b_2 u_2(t), \quad (38)$$

$x_3(t) = x_1(t) - x_2(t)$. The Simple analysis shows, that the law of the management $u(t)$ providing for object (38) conditions guaranteed fulfillment of admissible quality (18) has a following appearance:

$$u(t) = \quad u_2(t) \quad = u_1(t) -]\backslash k_{11} \quad k_{12} \quad k_{21} \quad 23 \quad \mathrm{r}x_1(t)\mathrm{i} \quad x_2(t) \quad x_3(t) \quad k_{13}, \quad k_{22} \quad k \quad (39)$$

Where

$k_{11} = k_1$, $k_{12} = 0$, $k_{13} = 0$, $k_{21} = k_3$, $k_{22} = k_3$, $k_{23} = k_5$.

3. Computer modelling of a control system. Entering into structure synthesized SAU engines of a direct current (fle1 and £B2) with independent excitation have following values of parameters:

$J_1 = 0{,}02\wedge.c^2$, $J_2(t_0) = 0{,}03\ K_Z\text{-}C^2$,

$A = 0{,}01\ K2\text{-}M^2/C$, $A = 0{,}015\ K2\text{-}M^2/C$,

$_m = 0{,}1 K_S.M^2.pad/(B.c^2)$, $_{V2} = 0{,}12 K_S.M^2.pad/(B.c^2)$.

Factors

~,=0,04, $k_2=0,03$, $c_1=0,16\times10^{-3}$, $c_3=60,5$, $c_4=0,5\times10^{-3}$.

The Control system should provide stabilization of following values of operated variables:

$$V_1^* = 3\ \square/\square, \qquad l^* = 0.$$

Thus factors of the equations of object (21) has a form

$$a_1 = -0{,}5c^{-1},\ b_1 = 5{,}0\ pad/(B\times c^2),$$

$$a_2 = \text{--\^{}}, \qquad b_2 = 0{,}0036\,r(t),$$

$$a3 = 0{,}16\times10^{-3}, \quad \sim_3 = a_2 + 6a_3, \qquad r(t_0) = 0{,}1M.$$

.

Under the conditions specified above following numerical values of parameters of the synthesized regulator are chosen:

$$p_1 = -1{,}2,\quad p_2 = 0,\quad p_3 = 0,\quad p_4 = -1{,}7,\quad g_2 = -1{,}9.$$

The block diagram of the synthesized control system of the electric drives, focused for computer modelling, it is shown on fig. 2.

Results of computer modelling nonlinear sistems at various entry conditions for a vector of a mismatch □ (t0) =x $_{(t0)}$ with use of program system Matlab/Simulink [5] are resulted on fig. 3 - 4, and control systems with the linear law of management -on fig. 5 - 6. Apparently from schedules of transients both systems provide the set engineering requirements on accuracy and speed. At the same time from the point of view of technical realization application of the linear regulator having the law of management (39) is more expedient.

Regulator Object of management

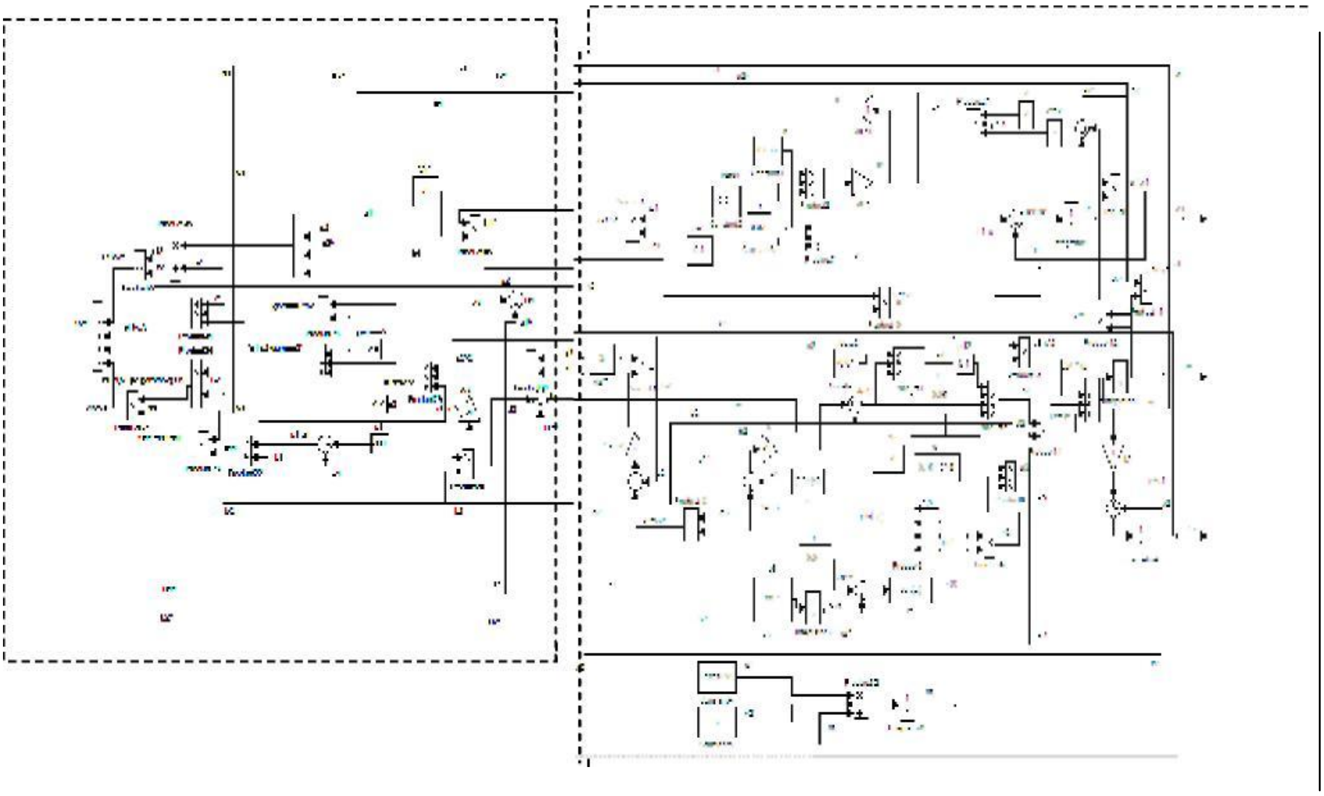


Fig. 2. The Block diagram of modelling on sistems.

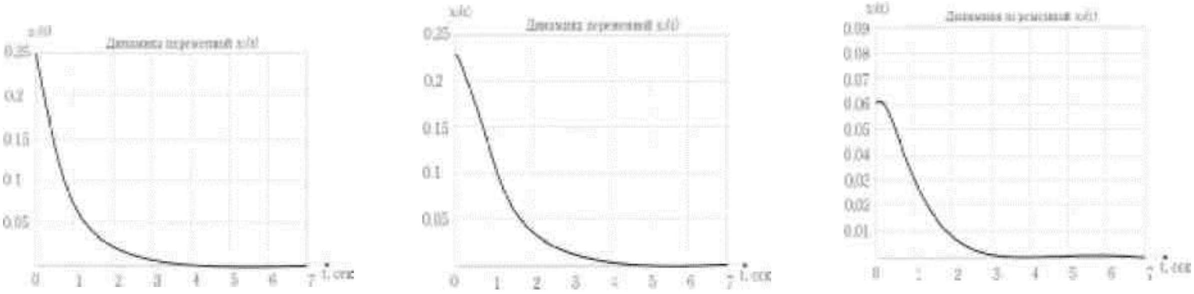
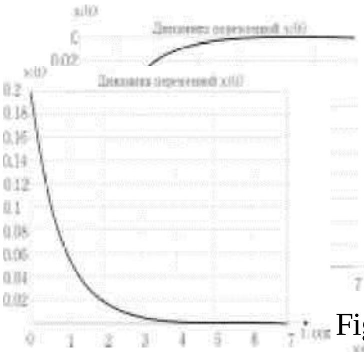


Fig. 3. Transients by mistake with the nonlinear law of management.



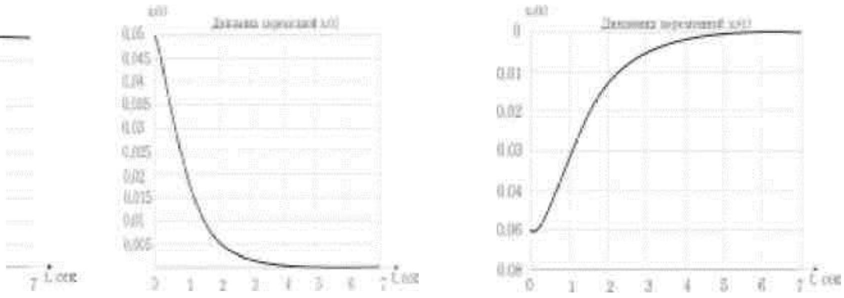


Fig. 4. Transients by mistake with the nonlinear law of management.

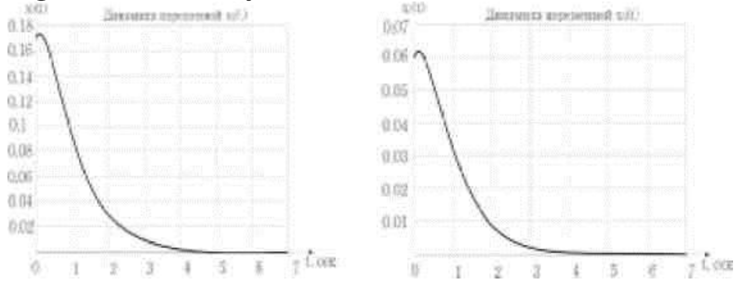


Fig. 5. Mistakes{errors} of regulation with the linear law of management.

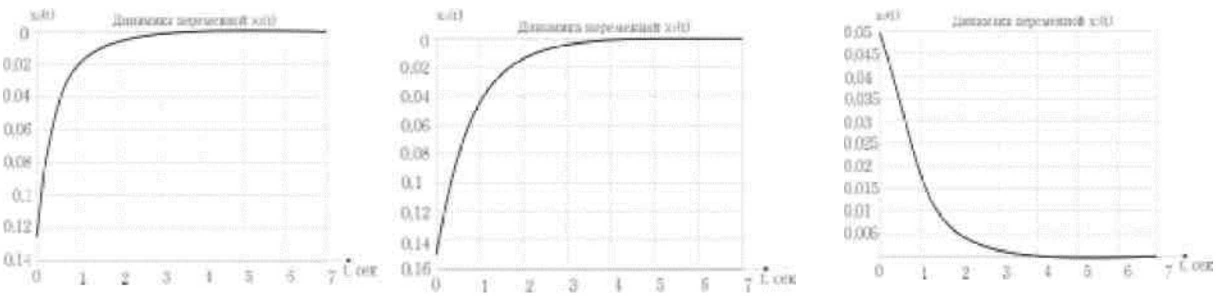


Fig. 6. Errors of regulation with the linear law of management.

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