Methods of information systems synthesis

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PARAMETRIC SYNTHESIS OF AN ELECTRO-HYDRAULIC EXECUTIVE DEVICE OF A DIGITAL SYSTEM OF AUTOMATIC CONTROL OF A MOVING OBJECT

Abstract. Most modern moving objects, including military moving objects, are equipped with guidance and stabilization systems with electro-hydraulic executive devices. Intercontinental ballistic missiles, space vehicles, aircraft, the main armament of tanks and ships have high-precision digital guidance and stabilization systems with electro-hydraulic actuators with potentiometric feedback, capable of ensuring high accuracy of stabilization of a moving object in a given direction. The work is devoted to the development of a methodology for selecting the value of the feedback channel amplification coefficient, which provides the maximum margin of stability and the maximum speed of the closed digital system of guidance and stabilization of a moving object. The proposed technique is based on the application of a discrete-continuous mathematical model of a closed digital system of guidance and stabilization of a moving object, which contains ordinary differential equations for describing the disturbed motion of the continuous part of the stabilized object, as well as difference equations for describing a discrete stabilizer. To construct the characteristic equation of a closed discrete system, the mathematical model is reduced to a system of difference equations using matrix series. At the same time, the number of considered members of the matrix series depends on the value of the quantization period of the digital stabilizer, therefore, in addition to determining the amplification coefficient of the feedback channel of the executive device, the proposed technique also includes the determination of the value of the quantization period of the digital stabilizer.

Keywords: guidance and stabilization system of a moving object; electrohydraulic executive device; quantization period of the digital stabilizer; margin of stability and speed of the closed-loop system.

Introduction

Problem statement. Electro-hydraulic actuators or electro-hydraulic amplifiers (EHA) are widely used in automatic control systems for moving objects and, above all, for military purposes objects. Guidance and stabilization systems for aircraft, missiles, spacecraft, ship and tank guns usually contain EHA, which make it possible to provide the required stability margin, high speed and accuracy of guidance and stabilization of these objects. The creation of high-precision systems of armaments and military equipment has led to the mass transition of automatic control systems for military facilities to a digital construction principle, which makes it possible to implement complex non-linear and non-stationary control algorithms that ensure high quality indicators of these types of armaments. The purpose of this work is to select the variable parameters of a digitally controlled EHA that provide high accuracy in processing control signals generated by an on-board digital computer (OBCM).

Main material

Mathematical model of the perturbed motion of the EHA. As an example, let us consider a schematic diagram of an EHA of a ballistic missile guidance and stabilization system that ensures turn of the combustion chamber of a liquid-propellant jet engine (LRE) [1, 2], shown in Fig. 1. The inputs of the onboard computer 1 receive signals from the outputs of the inertial sensors of angles, angular velocities and accelerometers that measure linear accelerations relative to the main central axes of inertia of the rocket, as well as signals from the outputs of the feedback potentiometers 14. The analog-to-code converter converts the onboard computer input signals into lattice functions, on the basis of which the guidance and stabilization algorithm is formed in the form of a lattice function $u_\Sigma[nT]$, which is converted by the code-to-analog converter into a continuous voltage function $u_\Sigma(t)$ supplied to the electromagnet input 2 which contain control windings 3 and 4, rocker arm 5 and fixing spring 6 holding rocker arm 5 in the neutral position at zero signals to windings 3 and 4. If the lattice function $u_\Sigma[nT]$ is positive, then a positive signal $u_\Sigma(t)$ goes to winding 3, and if the function $u_\Sigma[nT]$ is negative, then a positive signal $u_\Sigma(t)$ goes to winding 4. In the first In this case, the rocker arm 5 rotates by a positive angle $\beta(t)$ (counterclockwise), and in the second case, by a negative angle $\beta(t)$

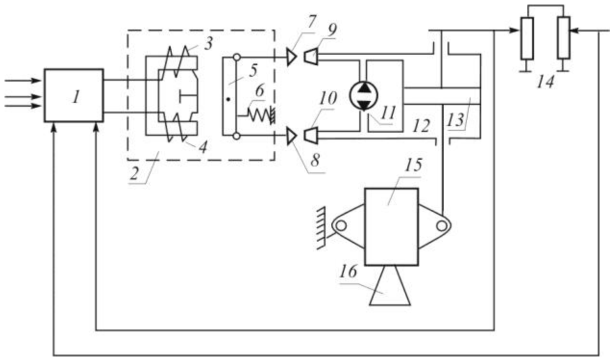

Fig. 1. Schematic diagram of an EHA of a ballistic missile guidance and stabilization system

(clockwise). The instantaneous value of the current in any of the control windings 3 or 4 is determined by solving the differential equation

$$L_y \frac{di(t)}{dt} + r_y i(t) = u_\Sigma(t), \quad (1)$$

where L_y is the inductance of the control winding; r_y – active resistance of the control winding; $u_\Sigma(t)$ is the signal at the output of the code-analogue converter corresponding to the lattice function

$$u_\Sigma[nT] = G[nT] - k_\delta \delta[nT], \quad (2)$$

where $G[nT]$ is the lattice function that determines the stabilization algorithm; $k_\delta \delta[nT]$ – lattice function of the feedback EHA by the angle of turn of the LRE combustion chamber.

When the rocker arm 5 is rotated by a positive angle $\beta(t)$, the needle 7 slightly opens the calibrated hole 9, and the needle 8 covers the calibrated hole 10. The pressure created by the hydraulic pump 11 decreases in the upper cavity of the hydraulic power cylinder 12, and increases in the lower cavity, causing the piston 13 to move up. The turn of the rocker arm 5 is described by the differential equation

$$I_k \frac{d^2\beta(t)}{dt^2} + f\frac{d\beta(t)}{dt} + c\beta(t) = k_\beta i(t), \quad (3)$$

and the displacement of the piston of the power hydraulic cylinder $s(t)$ is associated with the turn of the rocker arm 5 through the angle $\beta(t)$ by the dependence

$$\frac{ds(t)}{dt} = k_p \beta(t), \quad (4)$$

here I_k is the moment of inertia of the rocker arm; f is the coefficient of fluid friction along the axis of the rocker arm; c – stiffness coefficient.

And finally, the angle of turn of the LRE combustion chamber $\delta(t)$ is related to the moving of the piston $s(t)$ by the formula

$$\delta(t) = k_s s(t). \quad (5)$$

From relations (4) and (5) we have

$$\frac{d\delta(t)}{dt} = k_p k_s \beta(t). \quad (6)$$

We write differential equations (1) and (3) in the form

$$T_y \frac{di(t)}{dt} + i(t) = k_y u_\Sigma(t); \quad (7)$$

$$T_1^2 \frac{d^2\beta(t)}{dt^2} + T_2 \frac{d\beta(t)}{dt} + \beta(t) = \frac{k_\beta}{c} i(t). \quad (8)$$

where the following notation is accepted

$$T_y = \frac{L_y}{r_y}; \; k_y = \frac{1}{r_y}; \; T_1^2 = \frac{I_k}{c}; \; T_2 = \frac{f}{c}.$$

Differential equations (6)–(8) together represent a mathematical model of the continuous part of the EHA. The mathematical model of the discrete part of the EHA can be obtained from relation (2), if we put $G[nT] = 0$ in the latter. As a result, we have

$$u_\Sigma[nT] = -k_\delta \delta[nT]. \quad (9)$$

We write the mathematical models of the continuous and discrete parts of the EHA in normal form, for which we introduce the state vector of the EHA

$$X(t) = \begin{bmatrix} x_1(t) \\ x_2(t) \\ x_3(t) \\ x_4(t) \end{bmatrix} = \begin{bmatrix} i(t) \\ \beta(t) \\ \dot{\beta}(t) \\ \delta(t) \end{bmatrix}; \quad U(t) = u_\Sigma(t).$$

As a result, we have

$$\frac{dx_1(t)}{dt} = -\frac{1}{T_y} x_1(t) + \frac{k_y}{T_y} u_\Sigma(t);$$

$$\frac{dx_2(t)}{dt} = x_3(t); \quad (10)$$

$$\frac{dx_3(t)}{dt} = -\frac{1}{T_1^2} x_2(t) - \frac{T_2}{T_1^2} x_3(t) + \frac{k_\beta}{cT_1^2} x_1(t);$$

$$\frac{dx_4(t)}{dt} = k_p k_s x_2(t).$$

We write system (10) in the vector-matrix form

$$\dot{X}(t) = A \cdot X(t) + B \cdot U(t), \quad (11)$$

where the matrices *A* and *B* are written as

$$A = \begin{bmatrix} -\frac{1}{T_y} & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ \frac{k_\beta}{cT_1^2} & -\frac{1}{T_1^2} & -\frac{T_2}{T_1^2} & 0 \\ 0 & k_p k_s & 0 & 0 \end{bmatrix}; \; B = \begin{bmatrix} \frac{k_y}{T_y} \\ 0 \\ 0 \\ 0 \end{bmatrix}.$$

Let us write a difference equation connecting the initial state of the continuous part of the system $X[kT]$ with its final state $X[(k+1)T]$ at each discreteness period [3]

$$X[(k+1)T] = \Phi \cdot X[kT] + H \cdot U[kT], \quad (12)$$

where the matrices Φ and H are determined by the formulas:

$$\Phi = \sum_{i=0}^{\infty} \frac{1}{i!} A^i T^i; \quad (13)$$

$$H = \sum_{i=0}^{\infty}\left[\frac{1}{(i+1)!}A^i T^{i+1}\right]B. \qquad (14)$$

The number of terms of the matrix series (13) and (14) taken into account depends on the value of the discreteness period T. Usually, when using modern onboard computers with a small quantization period, it is assumed with sufficient accuracy

$$\Phi = E + A \cdot T; \qquad (15)$$

$$H = B \cdot T. \qquad (16)$$

We write relation (9) in the vector-matrix form

$$U[kT] = K \cdot X[kT], \qquad (17)$$

where the Kravna matrix is equal to

$$K = [0 \quad 0 \quad 0 \quad k_\delta]. \qquad (18)$$

Let us substitute relation (17) into difference equation (12). As a result, we obtain the difference EHA equation with digital feedback

$$X[(k+1)T] = [\Phi + H \cdot K] \cdot X[kT]. \qquad (19)$$

Let us write the characteristic equation of the EHA [3]

$$\det[\Phi + H \cdot K - E \cdot z] = 0. \qquad (20)$$

Substituting matrices (15), (16), and (18) into equation (20), we obtain

$$\det\begin{bmatrix} (1-z)-\frac{T}{T_y} & 0 & 0 & -k_y k_\delta \frac{T}{T_y} \\ 0 & 1-z & T & 0 \\ \frac{k_\beta T}{c T_1^2} & -\frac{T}{T_1^2} & (1-z)-\frac{T_2 T}{T_1^2} & 0 \\ 0 & k_p k_s & 0 & 1-z \end{bmatrix} = 0. \qquad (21)$$

Expanding the determinant (21), we write the characteristic equation of the EHA with digital feedback in the form

$$(1-z)^4 - (1-z)^3\left(\frac{T_2}{T_1^2}+\frac{1}{T_y}\right)T + (1-z)^2 \times \left(1+\frac{T_2}{T_y}\right)\frac{T^2}{T_1^2} - (1-z)\frac{T^3}{T_y T_1^2} + k \cdot k_\delta \frac{T^4}{T_y T_1^2} = 0, \qquad (22)$$

where the gain of the direct circuit of the EHA is equal to

$$k = \frac{k_y k_\beta k_p k_s}{c}. \qquad (23)$$

Parametric synthesis of EHA with digital feedback. Let us use the *w*-transformation method [4] and set in the characteristic equation (22)

$$z = \frac{1+w}{1-w}.$$

Then

$$1-z = -\frac{2w}{1-w}; \quad (1-z)^2 = \frac{4w^2}{1-2w+w^2};$$

$$(1-z)^3 = -\frac{8w^3}{1-3w+3w^2-w^3}; \quad (1-z)^4 = \frac{16w^4}{1-4w+6w^2-4w^3+w^4}. \qquad (24)$$

In the obtained relations (21), we will make the replacement [5] $w = \alpha + j\omega$. As a result, we get

$$1-z = \alpha_1(\alpha,\omega) + j\beta_1(\alpha,\omega);$$
$$(1-z)^2 = \alpha_2(\alpha,\omega) + j\beta_2(\alpha,\omega);$$
$$(1-z)^3 = \alpha_3(\alpha,\omega) + j\beta_3(\alpha,\omega);$$
$$(1-z)^4 = \alpha_4(\alpha,\omega) + j\beta_4(\alpha,\omega), \qquad (25)$$

where
$$\alpha_1(\alpha,\omega) = -\frac{2\left[\alpha(1-\alpha)-\omega^2\right]}{(1-\alpha)^2+\omega^2}; \qquad (26)$$

$$\beta_1(\alpha,\omega) = -\frac{2\omega}{(1-\alpha)^2+\omega^2}; \qquad (27)$$

$$\alpha_2(\alpha,\omega) = \frac{4\begin{bmatrix}\left(\alpha^2-\omega^2\right)\left(1-2\alpha+\alpha^2-\omega^2\right)- \\ -4\alpha\omega^2(1-\alpha)\end{bmatrix}}{\left(1-2\alpha+\alpha^2-\omega^2\right)^2+4\omega^2(1-\alpha)^2}; \qquad (28)$$

$$\beta_2(\alpha,\omega) = \frac{4\begin{bmatrix}2\omega(1-\alpha)\left(\alpha^2-\omega^2\right)+ \\ +2\alpha\omega\left(1-2\alpha+\alpha^2-\omega^2\right)\end{bmatrix}}{\left(1-2\alpha+\alpha^2-\omega^2\right)^2+4\omega^2(1-\alpha)^2}; \qquad (29)$$

$$\alpha_3(\alpha,\omega) = -\frac{8\left\{\begin{matrix}\left(\alpha^3-3\alpha\omega^2\right)\times \\ \times\left[1-3\alpha+3\left(\alpha^2-\omega^2\right)-\left(\alpha^3-3\alpha\omega^2\right)\right]+ \\ +\omega^2\left(-3+6\alpha-3\alpha^2+\omega^2\right)\left(3\alpha^2-\omega^2\right)\end{matrix}\right\}}{\left[1-3\alpha+3\left(\alpha^2-\omega^2\right)-\left(\alpha^3-3\alpha\omega^2\right)\right]^2+ +\omega^2\left(-3+6\alpha-3\alpha^2+\omega^2\right)^2}; \qquad (30)$$

$$\beta_3(\alpha,\omega) = -\frac{8\left\{\begin{matrix}-\left(\alpha^3-3\alpha\omega^2\right)\omega\left(-3+6\alpha-3\alpha^2+\omega^2\right)+ \\ +\left(3\alpha^2\omega-\omega^3\right)\times \\ \times\left[1-3\alpha+3\left(\alpha^2-\omega^2\right)-\left(\alpha^3-3\alpha\omega^2\right)\right]\end{matrix}\right\}}{\left[1-3\alpha+3\left(\alpha^2-\omega^2\right)-\left(\alpha^3-3\alpha\omega^2\right)\right]^2+ +\omega^2\left(-3+6\alpha-3\alpha^2+\omega^2\right)^2}; \qquad (31)$$

$$\alpha_4(\alpha,\omega) =$$

$$=\frac{16\left\{\begin{gathered}\left(\alpha^4-6\alpha^2\omega^2+\omega^4\right)\times\\ \times\left[\begin{gathered}1-4\alpha+6\left(\alpha^2-\omega^2\right)-\\ -4\left(\alpha^3-3\alpha\omega^2\right)+\\ +\left(\alpha^4-6\alpha^2\omega^2+\omega^4\right)\end{gathered}\right]+\\ +4\alpha\omega^2\left(\alpha^2-\omega^2\right)\times\\ \times\left[\begin{gathered}-4+12\alpha-4\left(3\alpha^2-\omega^2\right)+\\ +4\alpha\left(\alpha^2-\omega^2\right)\end{gathered}\right]\end{gathered}\right\}}{\left[\begin{gathered}1-4\alpha+6\left(\alpha^2-\omega^2\right)-4\left(\alpha^3-3\alpha\omega^2\right)+\\ +\left(\alpha^4-6\alpha^2\omega^2+\omega^4\right)\end{gathered}\right]^2+\omega^2\left[\begin{gathered}-4+12\alpha-4\left(3\alpha^2-\omega^2\right)+\\ +4\alpha\left(\alpha^2-\omega^2\right)\end{gathered}\right]^2}; \quad (32)$$

$$\beta_4(\alpha,\omega)=$$

$$=\frac{16\left\{\begin{gathered}4\alpha\omega\left(\alpha^2-\omega^2\right)\times\\ \times\left[\begin{gathered}1-4\alpha+6\left(\alpha^2-\omega^2\right)-\\ -4\left(\alpha^3-3\alpha\omega^2\right)+\\ +\left(\alpha^4-6\alpha^2\omega^2+\omega^4\right)\end{gathered}\right]-\\ -\left(\alpha^4-6\alpha^2\omega^2+\omega^4\right)4\omega\times\\ \times\left[\begin{gathered}-1+3\alpha-\left(3\alpha^2-\omega^2\right)+\\ +\alpha\left(\alpha^2-\omega^2\right)\end{gathered}\right]\end{gathered}\right\}}{\left[\begin{gathered}1-4\alpha+6\left(\alpha^2-\omega^2\right)-4\left(\alpha^3-3\alpha\omega^2\right)+\\ +\left(\alpha^4-6\alpha^2\omega^2+\omega^4\right)\end{gathered}\right]^2+\omega^2\left[\begin{gathered}-4+12\alpha-4\left(3\alpha^2-\omega^2\right)+\\ +4\alpha\left(\alpha^2-\omega^2\right)\end{gathered}\right]^2}; \quad (33)$$

Taking into account relations (25), the characteristic equation of the EHA with digital feedback (22) takes the following form

$$\begin{gathered}\alpha_4(\alpha,\omega)+j\beta_4(\alpha,\omega)-\\ -\left(T_2/T_1^2+1/T_y\right)T\left[\alpha_3(\alpha,\omega)+j\beta_3(\alpha,\omega)\right]+\\ +\left(1+\frac{T_2}{T_y}\right)\frac{T^2}{T_1^2}\left[\alpha_2(\alpha,\omega)+j\beta_2(\alpha,\omega)\right]-\\ -\frac{T^3}{T_yT_1^2}\left[\alpha_1(\alpha,\omega)+j\beta_1(\alpha,\omega)\right]+k\cdot k_\delta\frac{T^4}{T_yT_1^2}=0.\end{gathered} \quad (34)$$

We represent the value k_δ as the sum of the real and imaginary parts

$$k_\delta=\mathrm{Re}\,k_\delta+j\,\mathrm{Im}\,k_\delta.$$

Then from equation (34) we have

$$\mathrm{Re}\,k_\delta=\frac{T_yT_1^2}{kT^4}\left\{\begin{gathered}-\alpha_4(\alpha,\omega)+\\ +\left(\frac{T_2}{T_1^2}+\frac{1}{T_y}\right)T\alpha_3(\alpha,\omega)-\\ -\left(1+\frac{T_2}{T_y}\right)\frac{T^2}{T_1^2}\alpha_2(\alpha,\omega)+\\ +\frac{T^3}{T_yT_1^2}\alpha_1(\alpha,\omega)\end{gathered}\right\}; \quad (35)$$

$$\mathrm{Im}\,k_\delta=\frac{T_yT_1^2}{kT^4}\left\{\begin{gathered}-\beta_4(\alpha,\omega)+\\ +\left(\frac{T_2}{T_1^2}+\frac{1}{T_y}\right)T\beta_3(\alpha,\omega)-\\ -\left(1+\frac{T_2}{T_y}\right)\frac{T^2}{T_1^2}\beta_2(\alpha,\omega)+\\ +\frac{T^3}{T_yT_1^2}\beta_1(\alpha,\omega)\end{gathered}\right\}. \quad (36)$$

Using formulas (35), (36), taking into account relations (26)–(33) in the complex plane ($\mathrm{Re}\,k_\delta$, $\mathrm{Im}\,k_\delta$) we construct the boundary of the EHA stability region, assuming $\alpha=0$ and changing ω from zero to infinity. The straight line segment enclosed between the intersection points of the constructed curve and the real axis will determine the stability region of the EHA with digital feedback (Fig. 2).

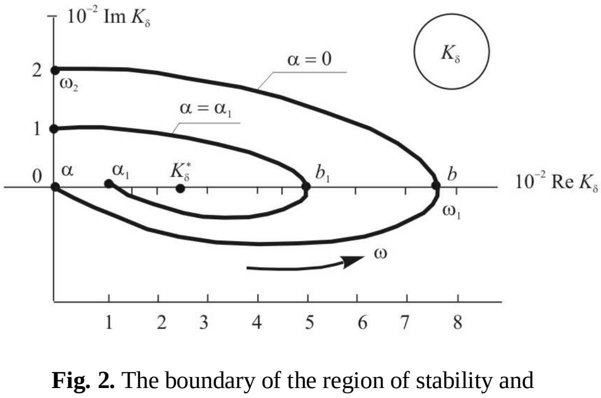

Fig. 2. The boundary of the region of stability and the line of equal degree of stability in the plane of the complex parameter k_δ

By changing the value of α in the negative direction $\alpha>\alpha_1$ and constructing lines of an equal degree of stability [5], on the real axis of the complex plane we will select segments a_1b_1, contracting at some $\alpha=\alpha^*$ to the point $k_\delta=k_\delta^*$, in which the stability margin EHA is maximum and equal to $\alpha=\alpha^*$.

The point k_δ^*, which ensures the maximum stability margin of the EHA, is located on the real axis of the complex plane K_δ. The segment $a_1 b_1$ contracts to this point. Point a_1 corresponds to $\omega = 0$ for each of the lines of equal degree of stability, consequently, the coordinate of point a_1 on the real axis of the complex plane K_δ is determined by the dependence

$$a_1(\alpha) = \frac{T_y T_1^2}{kT^4} \left\{ \begin{array}{c} -\alpha_4(\alpha,0) + \left(\dfrac{T_2}{T_1^2} + \dfrac{1}{T_y} \right) \times \\ \times T \alpha_3(\alpha,0) - \left(1 + \dfrac{T_2}{T_y} \right) \dfrac{T^2}{T_1^2} \times \\ \times \alpha_2(\alpha,0) + \dfrac{T^3}{T_y T_1^2} \alpha_1(\alpha,0) \end{array} \right\}, \quad (37)$$

where the quantities $\alpha_i(\alpha,0)$ can be obtained from relations (26), (28), (30) and (32) when substituting $\omega = 0$ in them:

$$\begin{gathered} \alpha_1(\alpha,0) = -\frac{2\alpha}{1-\alpha}; \quad \alpha_2(\alpha,0) = \frac{4\alpha^2}{(1-\alpha)^2}; \\ \alpha_3(\alpha,0) = -\frac{8\alpha^3}{(1-\alpha)^3}; \quad \alpha_4(\alpha,0) = \frac{16\alpha^4}{(1-\alpha)^4}. \end{gathered} \quad (38)$$

At the point k_δ^*, the value of $a_1(\alpha)$ reaches its maximum

$$k_\delta^* = \max_\alpha a_1(\alpha). \quad (39)$$

We differentiate the right side of dependence (38) with respect to α and equate the result of differentiation to zero

$$\begin{gathered} -\frac{\partial \alpha_4(\alpha,0)}{\partial \alpha} + \left(\frac{T_2}{T_1^2} + \frac{1}{T_y} \right) T \frac{\partial \alpha_3(\alpha,0)}{\partial \alpha} - \\ -\left(1 + \frac{T_2}{T_y} \right) \frac{T^2}{T_1^2} \frac{\partial \alpha_2(\alpha,0)}{\partial \alpha} + \frac{T^3}{T_y T_1^2} \frac{\partial \alpha_1(\alpha,0)}{\partial \alpha} = 0. \end{gathered} \quad (40)$$

As an example, consider an EHA with parameters k = 0,3664 V^{-1}; $T_y = 4 \cdot 10^{-2}$ s; $T_1^2 = 10^{-4}$ s^2; $T_2 = 0{,}55 \cdot 10^{-2}$ s. Then, taking into account relations (39), condition (40) takes the form:

$$\begin{gathered} \alpha^3 \left[-32 + 9{,}6 \cdot 10^2 T - 4{,}548 \cdot 10^4 T^2 + 0{,}25 \cdot 10^6 T^3 \right] + \\ + \alpha^2 \left[-9{,}6 \cdot 10^2 T + 9{,}1 \cdot 10^4 T^2 - 0{,}75 \cdot 10^6 T^3 \right] + \\ + \alpha \left[-4{,}548 \cdot 10^4 T^2 + 0{,}75 \cdot 10^6 T^3 \right] - 0{,}25 \cdot 10^6 T^3 = 0. \end{gathered} \quad (41)$$

The real negative and two complex-conjugate roots with negative real parts of the cubic equation (41) determine the value of the maximum stability margin α^* of the considered EHA.

EHA with digital feedback has two variable parameters – the gain of the feedback loop k_δ and the quantization period of the onboard computer T. The optimal value of k_δ^* in accordance with relations (37) and (39) is determined by the formula

$$k_\delta^* = \frac{T_y T_1^2}{kT^4} \left\{ \begin{array}{c} -\alpha_4(\alpha^*,0) + \left(\dfrac{T_2}{T_1^2} + \dfrac{1}{T_y} \right) T \alpha_3(\alpha^*,0) - \\ -\left(1 + \dfrac{T_2}{T_y} \right) \dfrac{T^2}{T_1^2} \alpha_2(\alpha^*,0) + \dfrac{T^3}{T_y T_1^2} \alpha_1(\alpha^*,0) \end{array} \right\}. \quad (42)$$

On Fig. 3 shows the root locus of the third-order polynomial (41) depending on the quantization period of the onboard computer. Points 1–6 of the root locus correspond to the following values of the quantization period T:
1 – $T = 1 \cdot 10^{-3}$ s; 2 – $T = 2 \cdot 10^{-3}$ s; 3 – $T = 4 \cdot 10^{-3}$ s; 4 – $T = 6 \cdot 10^{-3}$ s; 5 – $T = 8 \cdot 10^{-3}$ s; 6 – $T = 10^{-2}$ s.

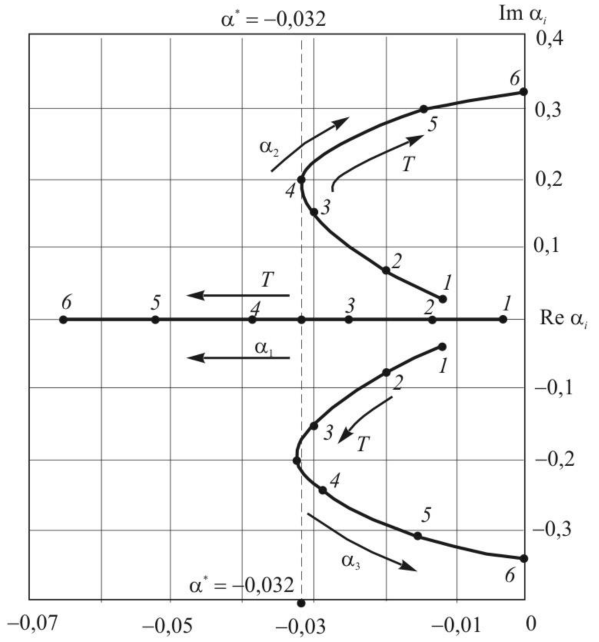

Fig. 3. Root locus of the polynomial of the third order (41)

A closed-loop EHA achieves a maximum margin of stability and speed in the case when the real parts of all three roots of the polynomial (41) are the same, and the roots themselves are located on a vertical dash-dotted line. In this case, the value α^* = –0,032, which corresponds to the value of the on-board computer quantization period $T = 5 \cdot 10^{-3}$ s. With a further increase in T, the stability margin and speed of the EHA decrease, and at $T = 10^{-2}$ s, the EHA loses stability.

Let us substitute α^* = –0,032 into relations (38)

$\alpha_1(\alpha^*,0)$ = 0,062; $\alpha_2(\alpha^*,0)$ = 0,00376;

$\alpha_3(\alpha^*,0)$ = 0,000233; $\alpha_4(\alpha^*,0)$ = 0,000141.

Then from relation (42) we find the optimal values of the coefficient of gain of the EHA feedback k_δ^* = 0,3664 V.

Conclusions

The variable parameters of the EHA with digital feedback are the feedback gain k_δ and the quantization period of the onboard computer T. It is recommended to choose the values of both variable parameters from the condition of ensuring the maximum margin of stability and speed of the closed-loop EHA.

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Параметричний синтез електрогідравлічного виконавчого органу цифрової системи автоматичного керування рухомим об’єктом

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Анотація. Більшість сучасних рухомих об’єктів, зокрема рухомих об’єктів військового призначення, оснащені системами наведення і стабілізації з електрогідравлічними виконавчими органами. Міжконтинентальні балістичні ракети, космічні апарати, літаки, основне озброєння танків і кораблів мають високоточні цифрові системи наведення і стабілізації з електрогідравлічними виконавчими елементами з потенціометричним зворотним зв’язком, здатними забезпечити високу точність стабілізації рухомого об’єкта щодо заданого напрямку. Робота присвячена розробці методики вибору значення коефіцієнта підсилення каналу зворотного зв’язку, що забезпечує максимальний запас стійкості і максимальну швидкодію замкненої цифрової системи наведення і стабілізації рухомого об’єкта. Запропонована методика базується на застосуванні дискретно-континуальної математичної моделі замкненої цифрової системи наведення і стабілізації рухомого об’єкта, що містить звичайні диференціальні рівняння для опису збуреного руху континуальної частини об’єкта, що стабілізується, а також різницеві рівняння для опису дискретного стабілізатора. Для побудови характеристичного рівняння замкненої дискретної системи математична модель приводиться до системи різницевих рівнянь із застосуванням матричних рядів. При цьому кількість врахованих членів матричних рядів залежить від величини періоду квантування цифрового стабілізатора, отже окрім визначення коефіцієнта підсилення каналу зворотного зв’язку виконавчого органу запропонована методика включає також визначення величини періоду квантування цифрового стабілізатора.

Ключові слова: система наведення і стабілізації рухомого об’єкта; електрогідравлічний виконавчий орган; період квантування цифрового стабілізатора; запас стійкості і швидкодія замкненої системи.