Adaptive System of Precision Control with a Reference Model

V.Yu. Rutkovsky, V.M. Glumov, V.M. Sukhanov
Institute of Control Sciences, Russian Academy of Sciences,
Profsoyuznaya 65, 117997, Moscow, Russia (e-mail : rutkov@ipu.ru)

Abstract: A new adaptation algorithm is proposed for adaptive systems with reference model operating independently from the intensity and spectral composition of the input actions and from the range and the rate of variations of parametric and coordinate disturbances. The problem of this algorithm realizability is considered. The results of simulation of the 6-order adaptive system are presented.

Keywords: adaptation algorithm, model reference, realization, control accuracy

1. INTRODUCTION

In the end of 1950-th-early in the 1960-th it was conceived the idea of designing of adaptive systems with a reference model (ASRM) (Whitaker et al., 1958; Donalson and Leonides, 1963; Hiza and Li, 1963; Parks, 1966; Zemlyakov and Rutkovsky, 1966; Landau, 1969; Yuan and Wonham, 1976; Morgan and Narendra, 1977 and others). Now hundreds of monographs and thousands of papers are devoted to the theory of this class of the control systems. The interest in ASRM is motivated by the constructive statement of the problem and by beauty of the mathematical tools involved. The existence of the reference model determines the goals of adaptation. And this implies the possibility of applying analogues of the feedback principle at the designing of the system. This demonstrates the constructive character of ASRM. The beauty of the mathematical tools is manifested in that the Lyapunov's methods is effectively used not only to the solution of the problem on motion stability but also to synthesis of the adaptation algorithms.

However, despite the intensive theoretical development of ASRM, the application of this class of systems in practice is rather modest, which is caused by a number of substantial shortcomings of ASRM. Specifically, the dynamic accuracy of ASRM motion depends on the intensity and spectral composition of input actions, on the rate of variations of parametric and coordinate disturbances, and on the rather detailed information on the state vector of the system. All these factors make the dynamics of ASRM motion low predictable, which discourages the developers of actual systems. Along with this, very high accuracy of motion (precision dynamics) is required in modern promising control system operating under uncertainty with regard to coordinate and parametric disturbances. By precision control, we mean a nearly zero error between the actual and some desired motion of a control system (motion of the reference model).

It is well known that the class of variable structure systems (VSS) was under active development for the control of nonstationary objects (Emel'yanov, 1967), (Utkin, 1974), (Krasnova and Utkin, 2006). In the VSS class, the system operation on the intensity and spectral composition of input actions and on the rate of variations in parametric and coordinate disturbances decreases to a substantial degree. However, the VSS class has its own shortcomings. For example, the range of parametric disturbances must be bounded. Another factor is that the coefficients of regulators vary in jump, which can adversely activate the neglected system dynamics.

In this paper, a new ASRM operation algorithm is proposed that combines the ASRM and VSS construction principles in the control of nonstationary systems so as to converge the positive properties of each of these principles and to smooth their negative properties. As the result proposed class of ASRM gets new properties. These properties include the independence of ASRM motion of the intensity and spectral composition of input actions, its independence of the range and the rate of variations of parametric and coordinate disturbances, and high dynamic accuracy of ASRM motion.

2. STATEMENT OF THE PROBLEM

Let us consider a control system obeying the following mathematical model (MM)

\[ d\varphi/dt + A(t)\varphi = B(t)g(t) + f(t) + S \]  

(1)

where \( t \) is time and \( t_0 \) is the initial point of considering, \( t \geq t_0 \); \( \varphi \in \mathbb{R}^n \), \( g \in \mathbb{R}^m \), \( f \in \mathbb{R}^r \) (\( m \leq n \)), are, respectively, the vectors of state, control action, and coordinate disturbance; \( A(t) \) and \( B(t) \) are matrices with unknown variable components; \( S \in \mathbb{R}^r \) is the vector of additional feedback, its components are used to compensate for the coordinate and parametric disturbances. The vectors \( \varphi(t) \) and \( g(t) \) are assumed to be measurable, their components are continuously differentiable functions.

The matrices \( A(t) \) and \( B(t) \) are represented in the form

\[ A(t) = A_0 + \Delta A(t), \quad B(t) = B_0 + \Delta B(t) \]  

(2)
Here \( A_0 \) and \( B_0 \) are the matrices that are chosen from the condition of the system desired reaction on the control action at \( f(t) = 0 \) and \( S = 0 \). \( A_0 \) is a Hurwitz matrix, \( \Delta A(t) \) and \( \Delta B(t) \) are unknown parametric disturbances, their components are continuously differentiable functions.

Equations (1) with regard to the correlation (2) are rewritten as

\[
\frac{d\varphi}{dt} + A_0\varphi = B_0g(t) + d(t) + S \tag{3}
\]

where \( d(t) = -\Delta A(t)\varphi(t) + \Delta B(t)g(t) + f(t) \) is a vector function with nonmeasurable components.

The goal is to find algorithms for varying the components of \( S \) so as to compensate for the influence of the disturbing vector \( d(t) \) on the motion of the system described by model (3). The problem is solved assuming that the components \( d(t), i = (1, n) \) of the vector \( d(t) \) are not bounded, whereas the rate of their variation is bounded, that is \( \|d(d(t))/dt\| \leq \mu_0, \ \mu_0 = \text{const} \), and numerical values of \( \mu_0 \) are given and can be rather large. So the object of our control system is essentially nonstationary.

### 3. Solution of the Problem Based on ASRM

Notice that in the considered case the equation of reference model will be as

\[
\frac{d\varphi_m}{dt} + A_0\varphi_m = B_0g(t) \tag{4}
\]

where \( \varphi_m \in \mathbb{R}^n \).

Algorithm of adaptation (algorithm for varying the components of \( S \)) is sought depending on measurable information so that \( \varphi(t) \) converges asymptotically to the motion \( \varphi_m(t) \) irrespective of the intensity and the spectral composition of the input disturbances or the ranges of parametric and coordinate disturbances with predictability and high dynamic accuracy of ASRM motion.

Introducing the notation

\[
\varepsilon = \varphi - \varphi_m, \quad y = d(t) + S, \quad d(d(t))/dt = \mu, \quad dS/dt = \psi \tag{5}
\]

we derive from (3) and (4) the system of equations

\[
\frac{d\varepsilon}{dt} + A_0\varepsilon = y, \quad \frac{dy}{dt} = \mu(t) + \psi \tag{6}
\]

Here, \( \psi = \psi(t, \varepsilon) \) is the desired algorithm of adaptation.

Consider the motion

\[
\varepsilon = 0, \quad y = 0 \tag{7}
\]

of system (6). The algorithm for varying \( \psi \) is chosen from the condition that the motion \( \varepsilon(t) \) and \( y(t) \) of system (6) converges asymptotically to (7). For this purpose, we define the Lyapunov function

\[
V(\varepsilon, y) = \chi(\varepsilon^TP\varepsilon) + y^Ty \tag{8}
\]

where \( \chi = \text{const} > 0 \), \( P \) is a symmetric positive definite matrix defined by the equality \(-(A_0^TP + PA_0) = Q \) and \( Q \) is a prescribed negative definite matrix.

In view of system (6), the time derivative of function (8) is

\[
\frac{dV(\varepsilon, y)}{dt} = \chi(\varepsilon^TP\dot{\varepsilon}) + 2y^T[\chi\dot{\varphi} + \mu(t) + \psi] \tag{9}
\]

where \( \sigma = P\varepsilon \).

The desired algorithm \( \psi \) is chosen from the condition \( dV(\varepsilon, y)/dt < 0 \) for \( \varepsilon \neq 0 \) and \( y \neq 0 \). For this purpose, we consider (Zemlyakov and Rutkovsky, 2009)

\[
\psi = -\chi\sigma - K\text{sign}(y) \tag{10}
\]

where \( K \) is diagonal matrix \( K = diag(k_1, ..., k_n) \) and \( \text{sign}(y) \) is a vector of the form \([\text{sign}(y_1), ..., \text{sign}(y_n)]\).

With regard for (10) equality (9) is rearranged in

\[
\frac{dV(\varepsilon, y)}{dt} = \chi(\varepsilon^TP\varepsilon) - 2y^T\rho(t) \tag{11}
\]

where \( \rho(t) = [\rho_1, ..., \rho_n] \) and \( \rho_i(t) = k_i - \mu\text{sign}(y_i), \ i = 1, n \).

Under the condition

\[
k_i > |\mu_i(t)| \tag{12}
\]

we have \( \rho_i(t) > 0 \), and it follows from (8) and (11) that

\[
V(\varepsilon, y) > 0, \quad dV(\varepsilon, y)/dt < 0 \tag{13}
\]

Inequalities (13), which were obtained irrespective of the form of the components of \( g(t) \) and \( d(t) \) under condition (12), ensure the asymptotic stability of the motion (7) of system (6).

We represent the MM of the system (6) with algorithm (10) as

\[
\frac{d^2\varepsilon}{dt^2} + A_0d\varepsilon/dt + \chi P\varepsilon = -R(t)\text{sign}(y) \tag{14}
\]

Here \( R(t) = \text{diag}(\rho_1(t), ..., \rho_n(t)) \) is a diagonal matrix. We can state that motion

\[
\varepsilon = 0, \quad d\varepsilon/dt = 0 \tag{15}
\]

is asymptotically stable. It should be noted two peculiarities of algorithm (10).

Firstly, system (14) goes over to the class of systems with mathematical models described by differential equations with discontinuous right-hand side. In such system, a sliding mode may occur on one or more surfaces of discontinuity. This problem requires a special consideration. But it is very important that sliding mode does not violate inequalities (13).

Secondly, algorithm (10) was obtained under the condition for measurability of the vector \( \text{sign}(y) \). However, it was not indicated how to acquire this information. Indeed, if one assumes that the vector \( y \) is measurable, then the problem of adaptation vanishes. This can be seen from the correlation \( y = d(t) + S \) where the vector \( d(t) \) is not measurable by problem formulation. It is obvious that the vector can be cal-
culated from the first equation of MM (6), but the derivative \( d\varepsilon/dt \) is not measurable.

In order to solve this contradiction the additional link is introduced in the system

\[
\tau \frac{dx}{dt} + x = \varepsilon
\]  

where \( x \in \mathbb{R}^n \), \( \tau = \text{const} > 0 \) is known small value.

Taking into consideration (16) the system motion is described as

\[
\tau d^2 x/dt^2 + (E + \tau A_0)dx/dt + A_0x = y, \quad dy/dt = \mu(t) + \psi \tag{17}
\]

Here \( E \in \mathbb{R}^{n\times n} \) is identity matrix. Now the vector \( dx/dt \) in the second order equation (17) is measurable.

Further it is required to solve the next problems: 1) what is the motion of the system (17) with the adaptation algorithm (10) at small but final values of \( \varepsilon \) or is there an interval of values of \( \varepsilon \) for which the motion \( x = 0, y = 0 \) asymptotically stable; 2) if such interval of \( \varepsilon \) does not exist then is there a domain into which the motion of the system (16) enters after a finite time interval from any initial point and remains there, at that the domain includes motion \( x = 0, y = 0 \)? If such domain does exist then what are its sizes? And we are to estimate these sizes in order to draw a conclusion about practical acceptability of the system.

Solution of these problems is considered below.

4. DYNAMICS OF PHYSICALLY REALIZABLE ASRM

For investigation of system (17) dynamics with adaptation algorithm (10) let us introduce the notations \( z = (z_1, z_2) \), where \( z_1 = x, z_2 = dx/dt \) and \( y = (y_1, y_2), y_1 = 0 \), and rewrite system (17) as

\[
dz/dt = A_1 z + Dy, \quad dy_2/dt = \mu + \psi, \tag{18}
\]

where block matrices \( A_1 \in \mathbb{R}^{2n\times 2n}, D \in \mathbb{R}^{2n\times 2n} \) are:

\[
A_1 = \begin{bmatrix}
0 & E \\
-\tau^{-1}A_0 & -\tau^{-1}(E + \tau A_0)
\end{bmatrix}, \quad D = \begin{bmatrix}
0 & 0 \\
0 & \tau^{-1}E
\end{bmatrix}.
\]

Let us consider nonperturbed motion

\[
z = 0, \quad y_2 = 0 \tag{19}
\]

Again Lyapunov’s function is chosen as

\[
V(z, y_2) = \chi(z^T P_2 z) + (y_2^T y_2) \tag{20}
\]

where \( \chi = \text{const} > 0 \), \( P_2 \in \mathbb{R}^{2n\times 2n} \) is a symmetric positive definite matrix defined by the equality \((A_1^T P_2 + P_2 A_1) = Q_1, \quad Q_1 \)

is a prescribed negative definite matrix, \((-A_1)\) is the Hurwitz matrix.

In view of system (19) the time derivative of function (20) at adaptation algorithm that is analog of algorithm (10) is

\[
\psi = -\chi \tau^{-1} P_2 z_1 - K \text{sign}(\varepsilon) \tag{21}
\]

\[
dV/dt = \chi(z^T Q_1 z) + 2\chi \tau^{-1}(y_2^T P_2 z_1) - 2(y_2^T \text{sign}(\varepsilon))^T \rho(t) \tag{22}
\]

Here \( N = z_2 + A_0 z_1, \ P_2 \in \mathbb{R}^{n\times n}, (i, j = 1, n) \) are blocks matrices of the matrix \( P_2 = \begin{bmatrix} P_{21} & P_{22} \\ P_{23} & P_{24} \end{bmatrix}, \quad K = \text{diag}(k_1, ..., k_n), \)

\[
[y_2 \cdot \text{sign}(\varepsilon)]^T = [\text{sign}(N_1), ..., \text{sign}(N_n)],
\]

\[
[y_2 \cdot \text{sign}(\varepsilon)]^T = [y_{21}(N_1), ..., y_{2n}(N_n)],
\]

\[
\rho(t)^T = \left[ \rho_1(t), ..., \rho_n(t) \right], \quad \rho_i(t) = k_i - \mu \text{sign}(N_i), \quad k_i > |\mu_i|,
\]

\[
\rho_i^\text{min} \leq \rho_i \leq \rho_i^\text{max}, \quad \rho_i^\text{min}, \rho_i^\text{max} > 0.
\]

But it is worth-while to consider a modified algorithm

\[
\psi = -\chi \tau^{-1} P_2 z_1 - \chi \tau^{-1} P_2 z_1 - K \text{sign}(\varepsilon). \tag{23}
\]

With this algorithm the Lyapunov’s function time derivative is

\[
dV/dt = \chi(z^T Q_1 z) - 2[y_2 \cdot \text{sign}(\varepsilon)]^T \rho(t) \tag{24}
\]

Expression (24) can be rewritten as

\[
dV/dt = \chi(z^T Q_1 z) - 2[y_2 \cdot \text{sign}(\varepsilon)]^T \rho(t) - 2\tau \left[ (z_1 + A_0 z_2) \cdot \text{sign}(\varepsilon) \right]^T \rho(t) \tag{25}
\]

where \( z_3 = dz_2/dt \).

From equality (25) it is obvious that this function is not negative definite one. Thus there is no interval of \( \varepsilon \) at which

\[
x = 0, \quad dx/dt = 0, \quad y_2 = 0 \tag{26}
\]

or

\[
x = 0, \quad dx/dt = 0, \quad d^2 x/dt^2 = 0 \tag{27}
\]

is asymptotically stable.

But derivative (24) in the domain

\[
-\chi(z^T Q_1 z) > 2[y_2]^T \rho(t) \tag{28}
\]

takes only negative values.

Therefore it is possible to guarantee: all phase trajectories of phase space of \( 3n \)-dimension from any initial position at \( t = t_0 \) into domain \( V(z_{20}, y_{20}) > 0, \ dV(z_0, y_{20})/dt < 0 \) after a finite time interval enter into the domain that contains the origin of coordinates and is limited from above by closed surface

\[
V(z, y_2) = C_k, \quad C_k = V(z_0, y_{20}) \tag{29}
\]

Here \( z_{20}, y_{20} \) is the solution of equation (28) at replacement of symbol of inequality on the symbol of equality.

Domain (29) determines the guaranteed accuracy of the control system. But it is very important to note that this estimation of the system guaranteed accuracy is very understated. Real accuracy is much higher.
From the expression (25) it follows that one can choose very small value of \( \tau \) at which the guaranteed accuracy can be considered as precision one. At \( \tau = 0 \) the derivative (25) coincides with the expression (11).

Let us reduce equation (16) taking into account algorithm (23) to the form

\[
\frac{d^2 x}{dt^2} + (E + \tau A_\theta) \frac{d^2 x}{dt^2} + \left( \frac{2}{\tau} P_{22} + A_\theta \right) \frac{dx}{dt} + \frac{2}{\tau} P_{12} x = -R(t) \text{sign}(N), \quad R(t) = \text{diag}(\rho_1(t), \ldots, \rho_n(t)).
\]

(30).

Characteristic equation that corresponds to equation (30) defines the interval \( 0 \leq \tau < \tau_0 \) of values \( \tau \) at which all phase trajectories enter into domain (29). Such interval exists in any case because the matrix \((-A_\theta)\) is Hurwitz one.

In the phase space \((z, y)\) the sliding modes can occur on one or more discontinuity surface \( y_i = 0, i = 1, n \).

5. EXAMPLE

As an example let us consider the system of the second order that is described by equation (1). The matrices \( A(t) \) and \( B(t) \) are

\[
A(t) = \begin{bmatrix}
0,5 - \sin 0,05\pi t & -\sin 0,05\pi t \\
0,3 - 0,6 \sin 0,05\pi t & 0,3 - 0,8 \sin 0,05\pi t
\end{bmatrix}
\]

\[
B(t) = \begin{bmatrix}
4,7 + 0,5 \sin 0,04\pi t & 0,6 + 0,5 \sin 0,01\pi t \\
0,9 + 0,4 \sin 0,02\pi t & 5,8 + 0,3 \sin 0,03\pi t
\end{bmatrix}
\]

(31)

One can see from the expressions (31) that matrix \( A(t) \) elements are harmonic functions with the period \( T = 40s \). At \( t = 0 \) the elements \( a_{11}(0) = 0,5s^{-1}, a_{22}(0) = 0,3s^{-1} \), at \( t = 10s \) they are \( a_{11}(10) = a_{22}(10) = -0,5s^{-1} \) and at \( t = 30s \) they have their maximal values \( a_{11}(30) = 1,5s^{-1}, a_{22}(30) = 1,1s^{-1} \). Maximal rates of the elements \( a_{ij}(t) \), \( i, j = 1,2 \) are situated in the range \((0,1 + 0,16)s^{-2}\). Hence the object of considered control system is essentially nonstationary so that the system is unstable for approximately 12s from \( T = 40s \). The vectors of the control action \( g \in R^2 \) and the coordinate disturbance \( f \in R^2 \) are taken as the following

\[
g(t) = \begin{bmatrix}
1,5 \sin t \\
1,7 \sin \pi (0,5t - 0,4)
\end{bmatrix}
\]

\[
f(t) = \begin{bmatrix}
1,2 \sin (2t + 0,5) + 0,8 \sin 3t \\
0,6 \sin (2,5t + 0,4) + 0,5 \sin 5t
\end{bmatrix}
\]

(32)

Graphs of the functions (32) are depicted in Fig. 1.

Maximal rates of change of the vector \( g(t) \) elements are:

\[
(g_1)_{max} = 1,5s^{-1}, (g_2)_{max} = 2,67s^{-1}, \quad \text{of the vector } f(t):

(f_1)_{max} \approx (f_2)_{max} \approx 2,5s^{-1}.
\]

The graphs of change of the vector \( \mu(t) = d(d(t))/dt \) components are shown in Fig. 2.

As the reference model was taken the system (4) where the matrices \( A_\theta \in R^{2x2} \) and \( B_\theta \in R^{2x2} \) were chosen from the condition of desired quality of the system reaction on the control action \( g(t) \) at zero initial values \( \varphi_{m}(0) = \varphi_{d}(0) = 0 \). Numerical values of these matrices elements are:

\[
A_\theta = \begin{bmatrix}
2,5 & 0,8 \\
1,3 & 4
\end{bmatrix}, \quad B_\theta = \begin{bmatrix}
5 & 1 \\
1,2 & 6
\end{bmatrix}
\]

(33)

The time constant of the additional link (15), where \( \tau \in R^2 \), was \( \tau = 0,01s \).

As the negative definite matrix \( Q_\tau \) was chosen the matrix

\[
Q_\tau = \text{diag}(-4,-6,-4,-4)
\]

(34)

for which the next blocks

\[
P_{21} = \begin{bmatrix}
0,0138 & 0,0105 \\
-0,0111 & 0,0054
\end{bmatrix}, \quad P_{22} = \begin{bmatrix}
0,0196 & -0,0003 \\
-0,0003 & 0,0289
\end{bmatrix}
\]

(35)
of the matrix $P_i$ were obtained.

Algorithm of adaptation was chosen in the form of correlation (23) where $\chi = 0.5$, $k_i = 25$ ($i = 1, 2$), and ideal relay function $\text{sign}(N)$ was replaced on the one

$$
\Phi(N) = \begin{cases} 
1 & \text{at } N \geq \Delta, \ N > 0, \\
-1 & \text{at } N \leq \Delta, \ N < 0, \\
\Delta = 0.004.
\end{cases}
$$

(36)

It is significant that at $k_2 = 25$ the condition $k_2 > |\mu_2|$ is broken during short intervals of time (Fig 2).

The common degree of the mathematical model of considered adaptive system is equal to 6. But for engineers the coordinates $\phi_1(t)$ and $\phi_2(t)$ or coordinates $1(t)$ and $2(t)$ are of most interest, because of the coordinates $\phi_1(t)$ and $\phi_2(t)$ are the ones of the real system. Others are the coordinates of the adaptation contour that is realized on the computer.

The results of computer simulations of the system's dynamic in reference to the coordinates $\phi_M(t) = (\phi_M1, \phi_M2)$ and $\varepsilon = (\varepsilon_1, \varepsilon_2)$ at $\varepsilon_1(0) = 2, \varepsilon_2(0) = -1.5$ are shown in Fig 3. It was considered the time interval from $t = 0$ to $t = 10s$ that is equal to the one fourth of the period $T$. It is seen from Fig 3 that the error $\varepsilon(t)$ converges to the very small value aperiodically and the error $|\varepsilon_2(t)|$ increases at first but then it decreases to the very small value too. At the intervals $5 < t < 6s$ and $7 < t < 8s$ the errors $|\varepsilon_1(t)| < 0.01$, $|\varepsilon_2(t)| < 0.06$. At $t > 10s$ they are $\varepsilon_1(t) = \varepsilon_2(t) \approx 0$.

In order to estimate of the system dynamic and the accuracy of the system's control a projection of the phase space (or that is more exactly of the state space) on the plane $(\varepsilon_1, \varepsilon_2)$ was constructed (Fig 4). In Fig. 4 twelve trajectories for different initial conditions are shown. All trajectories converge to the small domain containing origin of coordinates.

Further they go into aforementioned small domain which is much less than domain defined by correlation (29). Really in this domain $|\varepsilon_1| < 0.005$ and $|\varepsilon_2| < 0.006$.

The motion in the neighborhood of the origin of coordinates takes place in the form of "real" sliding mode. The amplitude of this mode is very small.
At other initial conditions the projections of the state space on the plane \((\epsilon_1, \epsilon_2)\) in the neighborhood of the origin of coordinates is practically the same which we have for the trajectories 8 and 13. The left and the right loops of the "eight" reaching the values \(\epsilon_1 = -0.01\) and \(\epsilon_2 = 0.06\) and the values \(\epsilon_1 = 0.0075\), \(\epsilon_2 = 0.035\) for the trajectory 8 correspond to time intervals \(5 < t < 6 s\) and \(7 < t < 8 s\) (Fig. 3). At \(t > 8 s\) the control accuracy is approximately 0.005.

Suggested algorithm suppresses effectively persistent disturbances \(f(t)\) in the case when control action \(g(t) = 0\) too. Practically the curves \(\epsilon_1(t)\) and \(\epsilon_2(t)\) are the same as for the case \(g(t) \neq 0\). After extinguishing of nonzero initial conditions the stabilization accuracy is equal to 0.001 approximately.

Dynamics of considered system with suggested algorithm was investigated at the random noise in the actions (32) and at the values of the adaptation contour parameters \(\chi = 0.5\), \(k_3 = 25\), \(\Delta = 0.004\). As the noise were considered white ones with dispersions \(D_{g1} = D_{g2} = 0.5\) and \(D_{g1} = D_{g2} = 0.4\).

Such values of the dispersions are equal to \((30-40)\%\) from the amplitudes of the harmonic control actions and disturbances.

Fig. 6. Projection of the state space on the plane \((\epsilon_1, \epsilon_2)\) at the presence of noise.

The projection of the system state space on the plane \((\epsilon_1, \epsilon_2)\) in the neighborhood of the coordinates origin for the considered case (trajectory 8) is depicted in Fig. 6. The trajectory configuration on the plane \((\epsilon_1, \epsilon_2)\) does not undergo of the principal variations in comparison with the case when the noise are absent. But the sizes of the "eight" left loop have increased approximately in three times just as the coordinate \(\epsilon_1\) so the coordinate \(\epsilon_2\) too \((5 < t < 6 s)\). The control accuracy is reduced from 0.006 to 0.02. But nevertheless the control system has high precision.

6. CONCLUSION

The new ASRM adaptation algorithm was obtained without assumption about quasistationarity of the regime of object functioning. It affords high control precision independently of the intensity and spectral composition of the input actions. But proposed algorithm requires to measure the full system state vector. So it can be considered only as a limit algorithm. But it was synthesized using the sufficient conditions for asymptotic stability of nonperturbed motion (19). Taking into consideration the results of computer simulation of some examples which have common sense it may be state that proposed algorithm allows to be simplified. At this the motion will not be asymptotically stable, but is possible to get very small value of the error \(\epsilon\).

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