International Journal of Applied Engineering Research ISSN 0973-4562 Volume 10, Number 24 (2015) pp 45027-45033

Quasi Adaptive Automatic Control System Synthesis With A Reference Model For Multiple Connected Object With State Delays

AsanovAskhatZamilovich, Valery SergeevichKarimov
Kazan Federal University, Kremliovskayastr, 18, 420008, Kazan, Russian Federation

Abstract-The implementation of complex object control laws, including multiple connected ones has various difficulties caused by numerous factors: the presence of non-linearities in the communication channels of an object, incomplete information about object parameters, the impossibility of a control object state vector measurig, etc. An important factor complicating the implementation of control laws, is the presence of non-linearities in the control channels of an object. These nonlinearities are presented by delays. The delays, which are concentrated in the communication channels of a control object, may lead to self-oscillation, the deterioration in the quality of management processes and even to the loss of a system stability. The proposed synthesis method is based on the method of matrix canonization and system introduction technologies. A set of solutions concerning the synthesis problem of a quasi adaptive automatic control systems with a reference model for multi connected object with state delays was received in this paper. The conditions of these solution existence were determined during the synthesis concerning the forced component of mismatch for a closed dynamic system that allow us to find the set of observer and regulator matrices satisfying control law.

The novelty of the proposed method is to form the set of equivalent control laws in an analytical form and to obtain the conditions of a set of synthesis problem solution existence before the formation of a problem solution.

The results of digital simulation confirm the delay compensation according to the state and the achievement of the desired processes in a control system.

The proposed method of synthesis may be used to manage complex technical objects with delays (such as mobile objects).

Keywords: object with the delays by state, system introduction technology, reference model, quasi adaptive system.

1. INTRODUCTION

The implementation of control laws by complex objects, including multiple connected ones, is related with various difficulties caused by numerous factors: the presence of non-linearities in the object communication channels, incomplete information about the parameters of an object, the impossibility of measuring a control object state vector, etc. There is a lot of such examples in the aircraft systems [1, 2], where the control objects are often non-linear ones, has a multiple connection and are not completely observable.

The solution of analytical design problems concerning the effective control systems by complex multiple related objects operating in conditions of uncertainty, both in parametric ones and in external environment is possible to develop in a class of adaptive systems. The methods of adaptive control synthesis for simply connected objects may be considered sufficiently well developed, for example in [3, 4]. At the same time, the use of "classical" methods is mainly difficult due to the set of requirements and conditions for the adaptation problem solution. Besides, most of aircraft real control objects are related multiply and the emerging challenges of control algorithm design are solved only with the use of a matrix system, in particular the methods of matrix inequalities and matrix introduction technologies [5, 6]. The absence (the inability to measure) of a number of quantities characterizing the state of an object and required for an effective management is possible to compensate by the use of observers (full and/or reduced ones) [7, 8].

The use of classical adaptation methods for the case of a multiple system is significantly complicated due to a number of factors. However, both in theory and in practice of automatic control the systems closing by its properties to adaptive ones are applied (they are called quasi adaptive for brevity). Their main advantage is the simplicity of technical implementation, conditioned mainly by the lack of adjustment chains for regulator ratios [2, 9, 10]. These systems include the systems of indirect disturbance measuring, parametrically invariant compensation systems, the systems with the introduction of extra working information in a management contour, the systems with high-gain ratio, different low-sensitivity schemes of automatic control systems (ACS). Such quasi adaptive kind of systems may include the automated systems with a reference model (ASRM) equivalent to adaptive systems by its properties under certain operation conditions. In ASRM the consistency of indicator quality during the change of an object parameters is achieved by the organization of multi mode movements in ACS, where all the changes of variable parameters are transferred into the changes of "fast" partial movements that do not appear in a controlled coordinate [9]. At that a predetermined (desired) distribution of the system transfer function poles is developed, thereby providing the required dynamics and the quality of management.

The peculiarity of multiply connected control systems is the presence of system zeros [11], which may change the dynamics, controllability and observability of a system significantly. Complex objects, which are undoubtedly the aviation and technical systems require the formation of the system zero desired location, the use of different techniques ensuring the predetermined range of zeros [12, 13, 14]. An integrated application of different methods and techniques allows to perform an analytical design of adaptive control systems by multiple aircraft objects [15, 16]. An important factor complicating the implementation of control laws, is the presence of non-linearities in the control channels of an object. These nonlinearities may be represented by delays. The phenomenon of a delay negatively affects the behavior of automatic control systems. The delays, which are concentrated in the communication channels of a control object, may result in self-oscillation, in the deterioration of management process quality and even to the loss a system stability loss [17].

In this paper, in order to control a multiply connected object with state delays operating at the incompleteness of information on a state vector, the method of control law synthesis is offered, based on an analytical solution of the quasi adaptive ACS synthesis problem with a reference model and an observer. The definition task is set using the machine of system introduction technology [18], matrix transfer function (MTF) of a regulator and an observer, as well as the conditions which determine them, under which the behavior of a control system will be described by the desired MTF. The search of a control law will be carried out for the case of synthesis according to the forced component of a closed dynamic system mismatch.

2. SYNTHESIS PROBLEM SET

Let the behavior of a dynamic object with the concentrated delays will be performed in the form of the equations:

$$\dot{x}(t) = \sum_{i=0}^{l} A_i x(t-\tau_i) + Bu(t),$$
$$y(t) = Cx(t),$$
(1)

where $\tau_0 = 0,\quad 0 < \tau_1, \tau_2, ..., \tau_l$ – constant delay periods, $i = 0,1,...,l$, $u(t) \in R^s$ – object control vector, $y(t) \in R^m$ – output variable vector, $x(t) \in R^n$ – control object state vector. In our case the matrices A_i have the size $n \times n$, B – $n \times s$, C – $m \times n$. The components $A_i x(t-\tau_i)$ describe the delay of signals according to the time τ_i in the internal channels of a control object (CO). Also we assume that the system matrices A_i, B, C are such, that the system transfer zeros are absent [12, 13].

The initial conditions are set considering the delay of signals in a management object - we will consider formally the negative moments of time t<0, assuming that the object had the dynamic processes before the starting moment of time:

$$x(t) = \varphi_x(t),\ t_0 - \tau \le t \le t_0,$$

where τ is the maximum delay period.

Let an observing device calculating the current state vector $x(t)$ of an object is presented by the following equations:

$$\dot{\hat{x}}(t) = \sum_{i=0}^{l} A_i \hat{x}(t) + Bu(t) + L(y(t) - \hat{y}(t)),$$
$$\hat{y}(t) = C\hat{x}(t),$$
(2)

where $\hat{x}(t) \in R^n$ – the state vector of a monitoring device (i.e., the state vector of a monitoring device does not contain any delays), $\hat{y}(t) \in R^m$ – output vector of a monitoring device, L - an observer matrix with the size of $n \times m$.

The goal of management is to ensure that the behavior of a synthesized control systems close to the behavior of a reference model containing no delays, which is described in state space by the following equations:

$$\dot{x}_M(t) = A_M x_M(t) + B_M g(t),$$
$$y_M(t) = C_M x_M(t),$$
(3)

where $x_M(t) \in R^n$ – the state vector of an object reference model, $y_M(t) \in R^m$ – the vector of an object model output variables, A_M, B_M, C_M – reference model matrices of appropriate sizes, $g(t) \in R^s$ – control vector at the system input.

Let the control law is described by the matrix equation:

$$u(p) = g(p) - K(p)(\hat{x}(p) - x_M(p)),$$
(4)

where $K(p)$ – regulator MTFwith the size of $n \times s$.

The requirements to a synthesized control system is formalized on the basis of a disagreement signal $\Delta x = \hat{x} - x_M$. Let the proximity of the synthesized system behavior is characterized by reference matrix transfer function $E^g_{\Delta x}(p)$:

$$E^g_{\Delta x}(p) = E^g_{\hat{x}}(p) - E^g_{x_M}(p),$$

where $E^g_{\hat{x}}(p)$ – MTF from control actions for an object state assessment, $E^g_{x_M}(p)$ – MTFfrom control actions to an object model state, $E^g_{\Delta x}(p)$ – MTFfrom the control actions to the mismatch of an object and a model.

Problem: the CO (1), the state observer (2), the management goal (3) and the management law (4) require the obtaining of MTF regulator $K(p)$ and MTF observer $L(p)$ or the conditions determining them, at which ACS behavior (fig. 1) will be described by a desired MTF $E_{\Delta x}^{g}(p)$.

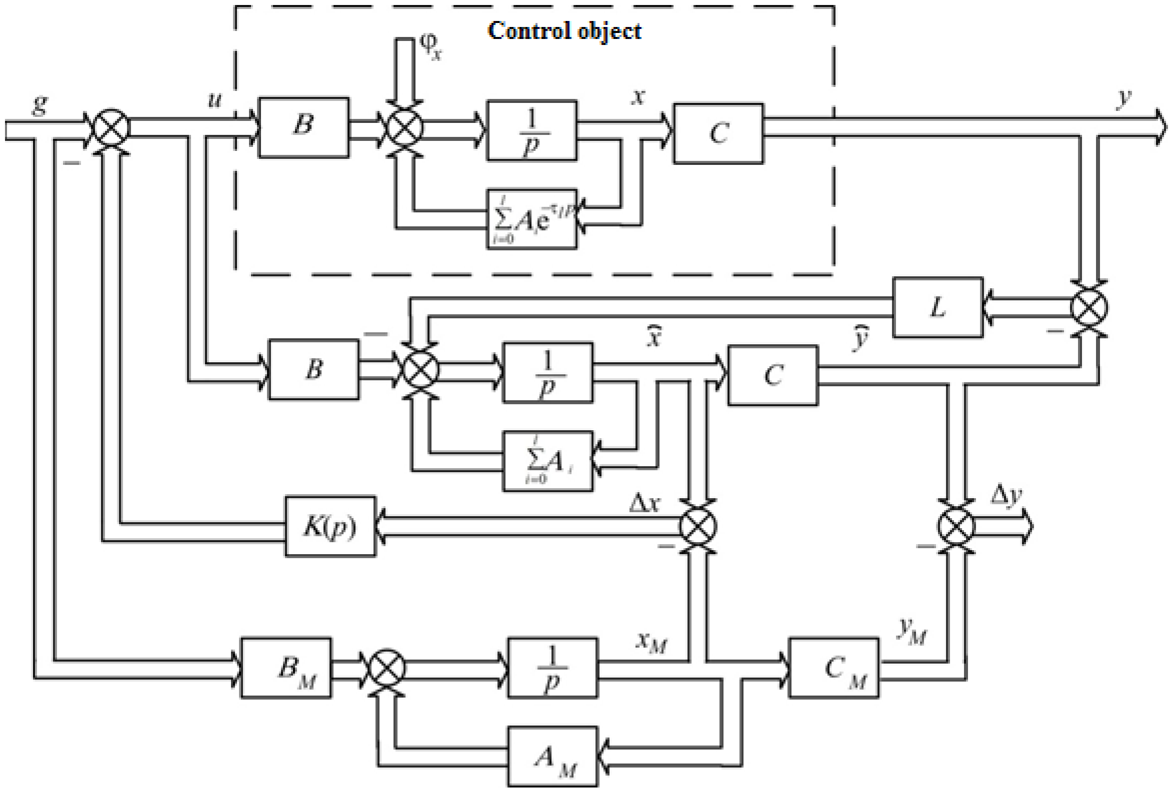


Fig. 1.Quasi adaptive control system with state delays

3. QUASI ADAPTIVE ACS SYNTHESIS WITH STATE DELAYS

During the synthesis of a control system we will use the system introduction technology [18, 19]. Taking into account the equations (1) - (4) and the procedures of the system introduction method a problematic matrix (promatrix) of a considered problem will be the following one:

$$\Omega(p)=\begin{bmatrix} (pI_n-\sum_{i=0}^{l}A_i e^{-\tau_i p}) & 0 & 0 & 0 & 0 & 0 & -B & 0 \\ 0 & (pI_n-\sum_{i=0}^{l}A_i) & 0 & -L(p) & L(p) & 0 & -B & 0 \\ 0 & 0 & (pI_n-A_M) & 0 & 0 & 0 & 0 & -B_M \\ -C & 0 & 0 & I_m & 0 & 0 & 0 & 0 \\ 0 & -C & 0 & 0 & I_m & 0 & 0 & 0 \\ 0 & 0 & -C_M & 0 & 0 & I_m & 0 & 0 \\ 0 & K(p) & -K(p) & 0 & 0 & 0 & I_s & -I_s \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & I_s \end{bmatrix}.$$

System promatrix in summary form is presented as follows

$$\Omega^{-1}(p)=\begin{bmatrix} E_x^{\varphi}(p) & * & * & * & * & * & * & E_x^{g}(p) \\ E_{\hat{x}}^{\varphi}(p) & * & * & * & * & * & * & E_{\hat{x}}^{g}(p) \\ E_{x_M}^{\varphi}(p) & * & * & * & * & * & * & E_{x_M}^{g}(p) \\ E_y^{\varphi}(p) & * & * & * & * & * & * & E_y^{g}(p) \\ E_{\hat{y}}^{\varphi}(p) & * & * & * & * & * & * & E_{\hat{y}}^{g}(p) \\ E_{y_M}^{\varphi}(p) & * & * & * & * & * & * & E_{y_M}^{g}(p) \\ E_u^{\varphi}(p) & * & * & * & * & * & * & E_u^{g}(p) \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & I_s \end{bmatrix}.$$

Here $E_j^i(p)$ – is MTF from the parameter *i* to the parameter *j*. The blocks which are not of interest in this study are marked by asterisks.

The matrices α and β, used in system introduction have the following form:

$\alpha=[0\ \ 0\ \ 0\ \ 0\ \ 0\ \ 0\ \ 0\ \ I_s]^T$, $\beta=[0\ \ I_n\ \ -I_n\ \ 0\ \ 0\ \ 0\ \ 0\ \ 0]$ at

$\omega=E_{\Delta x}^{g}(p)$,

where ω is the synthesized image of a system - the desired matrix transfer function.

After the performance of introduction technology procedures - serial matrix factorization $\Omega=\Sigma\Xi$, $\alpha=\Sigma\delta$, $\beta=\pi\Xi$, $\omega=\pi\delta$ (π, δ, Ξ, Σ – additional matrices), you may get the equation that must be satisfied the controller K(p) MTF at the synthesis according to a forced component $E_{\Delta x}^{g}(p)$ of Δx mismatch of a closed dynamic system.

In order to solve matrix equations, which are obtained as a result of introduction procedure application, the application of matrix canonization device is possible [20].

The application of introduction technology at the synthesis according to a forced constituent of Δx mismatch gives the following system of equations concerning the transfer of matrices *K*(*p*), *L*(*p*), π_x, $\pi_{\hat{x}}$, π_{x_M} :

$$\begin{aligned} &\pi_x(pI_n-\sum_{i=0}^{l}A_ie^{-\tau_i p})=\pi_{\hat{x}}LC,\\ &\pi_{\hat{x}}(pI_n-\sum_{i=0}^{l}A_i)=I_n-\pi_{\hat{x}}LC-(\pi_xB+\pi_{\hat{x}}B)K,\\ &\pi_{x_M}(pI_n-A_M)=-I_n+(\pi_xB+\pi_{\hat{x}}B)K,\\ &E_{\Delta x}^{g}=\pi_{x_M}B_M+\pi_xB+\pi_{\hat{x}}B. \end{aligned} \quad (5)$$

From the first equation of the system (5) using the apparatus of matrix canonization [20], we will obtain a set of an observer matrices L(p) in respect of unknown π_x and $\pi_{\hat{x}}$:

$$\{L(p)\}_{\eta,\mu}=\tilde{\pi}_{\hat{x}}\pi_x(pI_n-\sum_{i=0}^{l}A_ie^{-\tau_i p})\tilde{C}+\overline{\pi_{\hat{x}}}^{R}\eta(p)+\mu(p)\overline{C}^{L}. \quad (6)$$

The conditions for a set of solution existence (6) have the following form:

$$\begin{aligned} &\overline{\pi_{\hat{x}}}^{L}\pi_x(pI_n-\sum_{i=0}^{l}A_ie^{-\tau_i p})=0,\\ &\pi_x(pI_n-\sum_{i=0}^{l}A_ie^{-\tau_i p})\overline{C}^{R}=0 \end{aligned} \quad (7)$$

or

$$\begin{aligned} &\pi_x(pI_n-\sum_{i=0}^{l}A_ie^{-\tau_i p})=\pi_{\hat{x}}(\pi_{\hat{x}})^{\sim R}\xi(p),\\ &\pi_x(pI_n-\sum_{i=0}^{l}A_ie^{-\tau_i p})=\vartheta(p)C^{\sim L}C, \end{aligned} \quad (8)$$

where ξ(p), ϑ(p) are arbitrary fractional polynomial matrices of appropriate dimensions.

From the equation system (5) we will find the expressions for the matrices $\pi_{\hat{x}}$, π_{x_M}

$$\pi_{x_M}=-\left[\pi_x(pI_n-\sum_{i=0}^{l}A_ie^{-\tau_i p})+\pi_{\hat{x}}(pI_n-\sum_{i=0}^{l}A_i)\right](pI_n-A_M)^{-1}, \quad (9)$$

$$\{\pi_{\tilde{x}}\}_{\kappa} = \left[E^{g}_{\Delta x} + \pi_x ((pI_n - \sum_{i=0}^{l} A_i e^{-\tau_i p})(pI_n - A_M)^{-1} B_M) - B \right] \times$$

$$\times \overline{(B - (pI_n - \sum_{i=0}^{l} A_i)(pI_n - A_M)^{-1} B_M)} + \kappa(p) \overline{(B - (pI_n - \sum_{i=0}^{l} A_i)(pI_n - A_M)^{-1} B_M)}^{L}, \quad (10)$$

where $\kappa(p)$ – is an arbitrary fractional polynomial matrix of appropriate dimensions.

$$\left[E^{g}_{\Delta x} + \pi_x ((pI_n - \sum_{i=0}^{l} A_i e^{-\tau_i p})(pI_n - A_M)^{-1} B_M) - B \right] \times$$

$$\times \overline{(B - (pI_n - \sum_{i=0}^{l} A_i)(pI_n - A_M)^{-1} B_M)}^{R} = 0 \quad (11)$$

or

$$E^{g}_{\Delta x} + \pi_x ((pI_n - \sum_{i=0}^{l} A_i e^{-\tau_i p})(pI_n - A_M)^{-1} B_M) - B =$$

$$= \chi(p) \overline{(B - (pI_n - \sum_{i=0}^{l} A_i)(pI_n - A_M)^{-1} B_M)}^{L} \times \quad (12)$$

$$\times (B - (pI_n - \sum_{i=0}^{l} A_i)(pI_n - A_M)^{-1} B_M),$$

where $\chi(p)$ – is an arbitrary fractional polynomial matrix of appropriate dimensions.

From the equation system (5) we will find the expressionfor the matrix $K(p)$:

$$(\pi_x B + \pi_{\tilde{x}} B) K = I_n + \pi_{x_M} (pI_n - A_M). \quad (13)$$

Using the apparatus of matrix canonization from the equation (13) we will find the expression for a set of regulators $K(p)$:

$$\{K(p)\}_{\chi} = \widetilde{(\pi_x B + \pi_{\tilde{x}} B)} (I_n + \pi_{x_M} (pI_n - A_M)) + \overline{(\pi_x B + \pi_{\tilde{x}} B)}^{R} \chi(p), \quad (14)$$

where $\chi(p)$ – is an arbitrary fractional polynomial matrix of appropriate dimensions.

The conditions for the equation (13) solution, a thus the existence of numerous solutions (14) have the following form:

$$\overline{(\pi_x B + \pi_{\tilde{x}} B)}^{L} (I_n + \pi_{x_M} (pI_n - A_M)) = 0 \quad (15)$$

or

$$(I_n + \pi_{x_M} (pI_n - A_M)) = (\pi_x B + \pi_{\tilde{x}} B) \widetilde{(\pi_x B + \pi_{\tilde{x}} B)}^{R} \gamma(p), \quad (16)$$

where $\gamma(p)$ – is an arbitrary fractional polynomial matrix of appropriate dimensions.

Thus the solutions of synthesis problem (6) and (14) were obtained with the conditions of these solutions existence (7) or (8), (11) or (12), (13) or (14) at the synthesis according to forced constituent mismatch of Δx for a closed dynamic systems that allow us to find the set of matrices for an observer and a controller satisfying the control law (4).

The conditions for the existence of the matrix $\pi_{\tilde{x}}$ set of values (10) have the following form:

4.EXAMPLE

Let a multiplied control object with delays is represented by matrices in state space:

$$A_0 = \begin{pmatrix} -1 & 2 \\ -2 & -5 \end{pmatrix}, \quad A_1 = \begin{pmatrix} -1 & 0 \\ 0 & 0 \end{pmatrix}, \quad B = \begin{pmatrix} 1 & 0 \\ -1 & 1 \end{pmatrix}, \quad C = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$$

with the delay timeof $\tau_1 = 1$ s. The management objective will be the model of an object with the matrices in the state space:

$$A_M = \begin{pmatrix} -1 & 0 \\ -2 & -5 \end{pmatrix}, \quad B_M = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}, \quad C_M = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}.$$

Let's set the desired MTF from *g*entry to a mismatch signal Δx

$$E^{g}_{\Delta x}(p) = \begin{pmatrix} \dfrac{-2}{(p+3)(p+1)} & \dfrac{2}{(p+3)^2} \\ \dfrac{-4p+1}{(p+1)(p+3)(p+5)} & \dfrac{-4}{(p+3)^2(p+5)} \end{pmatrix}$$

and the fractional polynomial function π_x:

$$\pi_x = \begin{pmatrix} \dfrac{-4}{(p+3)^2(p+1)} & \dfrac{2}{(p+3)^2} \\ \dfrac{8}{(p+1)(p+3)^2(p+5)} & \dfrac{-4}{(p+3)^2(p+5)} \end{pmatrix}.$$

Let's verify the existence an observer matrix numerous values according to the following identities (7) and (11), by obtaining preliminary the following

International Journal of Applied Engineering Research ISSN 0973-4562 Volume 10, Number 24 (2015) pp 45026-45033

matrices $\overline{C}^R$, $\overline{\pi_{\tilde{x}}}^L$ and $\overline{(B-(pI_n-\sum_{i=0}^{l}A_i)(pI_n-A_M)^{-1}B_M)}^R$:

$$\overline{C}^R = 0,$$

$$\overline{(B-(pI_n-\sum_{i=0}^{l}A_i)(pI_n-A_M)^{-1}B_M)}^R = 0,$$

$$\overline{\pi_{\tilde{x}}}^L = 0.$$

Consequently, the conditions for the equation (6) solution are fulfilled, and you may move to an observation matrix obtaining. Let η(p) = 0 and μ(p) = 0, then the only solution of the equation (6) will be the following one:

$$L(p)=\begin{bmatrix}\dfrac{-4e^{-p}}{(p+3)^2} & 2\\ 0 & 0\end{bmatrix}.$$

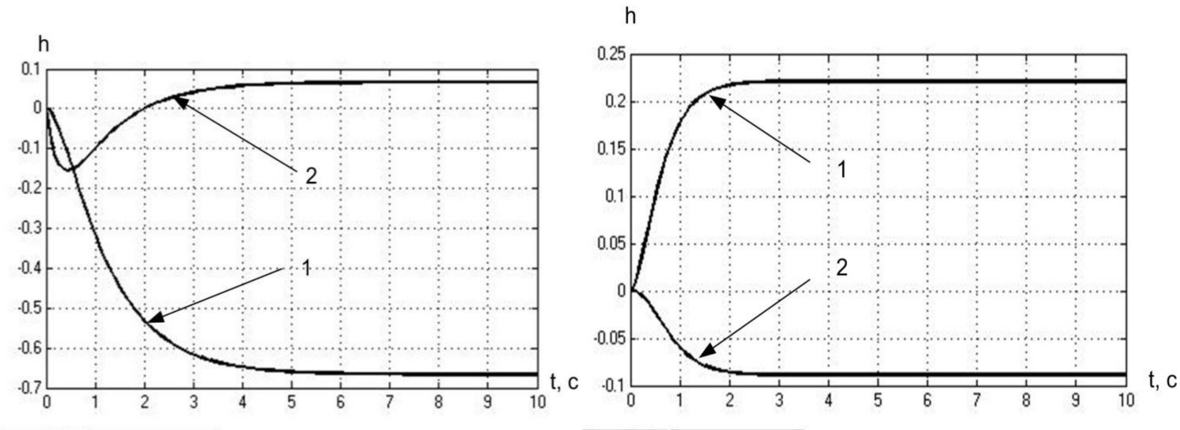
Let's check the condition of the equation (14) solvability to search the sets of regulators by obtaining a supporting matrix $\overline{(\pi_x B+\pi_{\tilde{x}}B)}^L$:

$$\overline{(\pi_x B+\pi_{\tilde{x}}B)}^L = 0.$$

Therefore, the identity (15) is performed and the equation (14) has a set of solutions. Suppose that the auxiliary matrix χ(p) = 0, then the only value of MTF controller obtained by the equation (14) will be the following one:

$$K(p)=\begin{pmatrix}\dfrac{4e^{-p}(p-1)}{(p+5)(p+1)^2} & \dfrac{-4e^{-p}}{(p+1)^2}\\ \dfrac{4e^{-p}(p-1)}{(p+5)(p+1)^2} & \dfrac{-4e^{-p}}{(p+1)^2}\end{pmatrix}.$$

Fig. 2 shows the graphs of transients processes for a quasi adaptive automatic control system, which coincide completely with transient processes of desired MTF from g entry to the mismatch signal Δx .



б)

Fig. 2.Transient characteristics of a quasi adaptive automatic control system (a – from the 1st input to the 1st and 2nd output, b - from the 2nd input to the 1st and 2nd output)

4. CONCLUSION

The results of digital simulation modeling confirm the delay compensation according to a state and the achievement of desired processes in a control system.

5. SUMMARY

The synthesis of an adaptive automatic control system was performed with a reference model for multi related object with the state delay. Many solutions to the problem of synthesis and the conditions for a problem solvability were found through the use of introduction technology system.

CONFLICT OF INTEREST

The author confirms that the presented data do not contain any conflict of interest.

ACKNOWLEDGEMENTS

The work is performed according to the Russian Government Program of Competitive Growth of Kazan Federal University.The work was financially supported by Russian Foundation for Basic Research (grant 14-08-00651).

REFERENCES

[1] Control and aiming of maneuverable unmanned aerial vehicles based on modern information technologies / ed. by M.N. Krasilschikov and G.G. Sebryakov. - M.: FIZMATLIT. - 2003. - 280 p.
[2] Rutkowski V.Y., Ilyasov B.G. et al. The adaptive control systems of aircraft gas turbine engines. - M.: Publishing House of MAI. - 1994. - 224 p.
[3] Miroschnik I.V., Nikiforov V.O., Fradkov A.L. The nonlinear and adaptive control of complex systems. SPb.: Nauka, 2000. - 549 p.
[4] V.A. Terekhov, I. Yu Tyukin. Adaptation in nonlinear dynamical systems. SPb.: LCI. - 2008. - 378 p.
[5] D.V. Balandin, M.M. Kogan. Synthesis of control laws based on linear matrix inequalities. - M.: FIZMATLIT. - 2007. - 280 p.

[6] Asanov A.Z., Dem'yanov D.N. Analytical synthesis of physically realizable regulators for multiple related objects based on introduction technology // Autometrics. - Novosibirsk: Publishing House of SO RAS, 2012. V. 48, № 5. pp.42-49.
[7] Asanov A.Z., Dem'yanov D.N. Analytical synthesis of functional observers // University news. Aviationequipment. 2013. - № 4.
[8] Asanov A.Z. Synthesis of electromechanical system load observer // University news. Aviationequipment. -Kazan. -2003. -№ 2. - pp.17-21.
[9] N.I. Sokolov, V.Y. Rutkowski, Sudzilovsky N.B. Adaptive automatic control system for aircrafts - M.: Engineering, 1988. - 208 p.
[10] Asanov A.Z. The synthesis of a complex rate control system equivalent to an adaptive one according to introduction technology // Mechatronics, Automation, Control. - 2003. - № 8. - pp. 2-8.
[11] E.M. Smagina. The issues of linear multidimensional objects analysis using the concept of a system zero. - Tomsk: Publishing House of Tomsk university. - 1990. - 160 p.
[12] Asanov A.Z., Dem'yanov D.N. The development of a desired location for the transmission zeros of multiple related dynamic system // University news. Aviationequipment. -2008. -№ 2. - pp. 17-22.
[13] Asanov A.Z., Dem'yanov D.N. The issues of improper analysis and synthesis of non-eigen dynamic systems taking into account transmission zeros // University news. Aviationequipment. -2009. -№ 2. - pp.24-28.
[14] Asanov A.Z., Dem'yanov D.N. Setting of zero range in control systems with parallel compensation // RAN news. Theoryandcontrolsystems. - Moscow, 2013. - № 5. - pp. 54-64.
[15] Asanov A.Z. Analytical design of an adaptive systems with a reference model // University news. Aviationequipment. -2003. -№ 3. - pp. 7-12.
[16] The synthesis of an adaptive systems with a reference model and an observer according to introduction technology // University news. Aviation equipment. -2004. -№ 2. - pp.21-25.
[17] Filimonov A.B. The spectral decomposition of systems with delays. Compensationofdelays. M.: FIZMATLIT. -2002. – 288 p.
[18] V.N. Bukov. Introduction of systems. Analytical approach to the analysis and synthesis of matrix systems. - Kaluga: The publishing house of the scientific literature named after N.F. Bochkareva, 2006. - 720 p.
[19] Asanov A.Z. Introduction system technology and its applications. - Ufa: Ufa state aviation techn. univ. - 2007. -227 p.
[20] V.N. Bukov, V.N. Ryabchenko, Kosyanchuk V.V. Zyabin E.Y. The solution of linear matrix equations by canonization method // Bulletin of Kiev University. Series: Physicalandmathematicalsciencies. - Issue 1. -2002. - pp. 19-28.