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STEADY ESTIMATION ALGORITHMS OF THE DYNAMIC SYSTEMS CONDITION ON THE BASIS OF CONCEPTS OF THE ADAPTIVE FILTRATION AND CONTROL

H.Z. Igamberdiyev[1], O.O. Zaripov[2] and A.N. Yusupbekov[3]
Department of Electronic and Automatic, Tashkent State Technical University, Tashkent, Uzbekistan
E-mail: [1]uz3121@mail.ru, [2]orif_zaripov@rambler.ru and [3]abek71@mail.ru

Abstract

Dynamic systems condition estimation regularization algorithms in the conditions of signals and hindrances statistical characteristics aprioristic uncertainty are offered. Regular iterative algorithms of strengthening matrix factor elements of the Kalman filter, allowing to adapt the filter to changing hindrance-alarm conditions are developed. Steady adaptive estimation algorithms of a condition vector in the aprioristic uncertainty conditions of covariance matrixes of object noise and the measurements hindrances providing a certain roughness of filtration process in relation to changing statistical characteristics of signals information parameters are offered. Offered practical realization results of the dynamic systems condition estimation algorithms are given at the adaptive management systems synthesis problems solution by technological processes of granulation drying of an ammophos pulp and receiving ammonia.

Keywords:

Dynamic System, Condition, Adaptive Filtration, Regularization, Regularization Parameter

1. INTRODUCTION

In the majority of management processes or multistep procedures of decision-making in technical and technological systems take place inherent in them uncertainty. This uncertainty doesn’t allow estimating precisely influence of managing directors of influences on quality of functioning of synthesized system. The uncertainty, existing both in the system, and in supervision, in many tasks can be presented as stochastic processes. Methods of stochastic management are applicable to such tasks. Often in the theory and practice of automation of management the type of stochastic management based on the assumption of performance of property of authentic equivalence is used. Generally this management isn't optimum. Property of divisibility is weaker in comparison with property of authentic equivalence. The principle of divisibility allows breaking a problem of optimum stochastic control into two independent subtasks: subtask of an optimum filtration or estimation and subtask of the optimum determined control. This circumstance once again indicates importance of a problem of dynamic estimation in the general theory of synthesis and creation of optimum control systems [1-4].

Optimum algorithms of estimation, identifications and control, which have received by present time considerable development, grow out of the decision of corresponding model problems in the presence of full a priori statistical information. In practice meet, as a rule, such situations in which a priori statistical information or is known approximately, or completely is absent [5-7]. In this case conditions of model problems are violated, the received algorithms of estimation become nonoptimal, and estimations formed by them can become untenable and, moreover, appear divergent. Above-mentioned causes necessity of supporting certain roughness of filter parameters to the factors noted above, i.e. Kalman filter adaptation [8-11].

Practical realization of parametric adaptive estimator meets the considerable difficulties of computing character connected with that circumstance, that at their formation it is necessary to consider the problems which decisions are unstable to small changes of initial data. Problems of similar type, in essence, are ill-conditioned. They belong to a class of ill-posed problems [12-15]. Thereupon working out of effective regular algorithms of steady estimation of dynamic systems conditions at parametric prior uncertainty and synthesis of computing circuits of their practical realization gets rather great value.

2. TASK STATEMENT

Let's consider the system described by the equations

$$x_{i+1} = A_i x_i + B_i u_i + \Gamma_i w_i, \qquad (1)$$

$$z_i = H_i x_i + v_i, \qquad (2)$$

where, x_i - state vector of system of dimension n; u_i - command vector of dimension l; z_i - a vector of observation of dimension m; w_i and v_i - vectors of object noise and disturbance of observation of dimension q and p accordingly, being sequence of a kind Gaussian white noise with characteristics

$$E[w_i] = 0,\ E\left[w_i w_k^T\right] = Q\delta_{ik},$$

$$E[v_i] = 0,\ E\left[v_i v_k^T\right] = R\delta_{ik},\ E\left[w_i v_k^T\right] = 0;$$

where, A_i, B_i, Γ_i and H_i - matrixes of corresponding dimensions, δ_{ik} - Kronecker symbol.

Let's use quadratic performance criterion

$$J_0 = E\left\{\sum_{k=0}^{N-1}\left(x_{k+1}^T \mathsf{P}_{k+1} x_{k+1} + u_k^T \mathsf{V}_k u_k\right)\right\}, \qquad (3)$$

where, weighting matrixes P_k are positive and semi-definite. In the assumption of existence of control law weighting matrixes of control V_k are accepted positive defined. A principal cause causing wide application of quadratic performance criterion, its convenience to analytical researches is.

As the system Eq.(1) is linear, and an initial state, noise and disturbances - Gaussian, its condition is Gaussian at any moment too. Besides, if to consider Gaussian character of noise and disturbances, and to assume linearity of Eq.(2) it is possible to make the assumption, that measurements will be Gaussian for all i too. It is possible to show [2, 5], that density $p(x_i \mid z^i)$ and $p(x_i \mid z^{i-1})$ are Gaussian for all i. A posteriori density $p(x_i \mid z^i)$ can be expressed through average $\hat{x}_{i|i}$ and covariance matrix $P_{i|i}$ of error of estimation. These statistics are defined Kalman filter equations:

$$\hat{x}_{i|i-1} = A_{i,i-1}\hat{x}_{i-1|i-1} + B_{i,i-1}u_{i-1}, \tag{4}$$

$$\hat{x}_{i|i} = \hat{x}_{i|i-1} + K_i\left[z_i - B_{i,i-1}u_{i-1} - H_i\hat{x}_{i|i-1}\right], \tag{5}$$

where, $K_i = P_{i|i-1}H_i^T\left[H_iP_{i|i-1}H_i^T + R_i\right]^{-1}$,

$$P_{i|i-1} = A_{i|i-1}P_{i-1|i-1}A_{i|i-1}^T + Q_{i-1}, \tag{6}$$

$$P_{i|i} = P_{i|i-1} - K_iH_iP_{i|i-1},$$

and initial conditions are

$$\hat{x}_{0|-1} = \mu_0,\ P_{0|-1} = M_0.$$

The Eq.(4) – Eq.(6) describe an average, covariance and, hence, Gaussian a posteriori density function for the system corresponding to the Eq.(1) – Eq.(2). Then control strategy minimizing performance criterion Eq.(3) at restrictions of a kind Eq.(1) and Eq.(2), is formed on the basis of equation:

$$u_i = -\Lambda_{i+1}A_{i+1,i}x_i,$$

where, $\Lambda_{i+1} = \left(\Gamma_{i+1,i}^T\Pi_{i,i+1}\Gamma_{i+1,i} + \mathrm{V}_i\right)^{-1}\Gamma_{i+1,i}^T\Pi_{i,i+1}$,

$$\Pi_{i|i+1} = A_{i+1,i}^T\Pi_{i+1,i+1}A_{i+1,i} + \mathrm{P}_i,$$

$$\Pi_{i|i} = \Pi_{i|i+1} - \Pi_{i|i+1}\Gamma_{i+1,i}\Lambda_{i+1},$$

$$\Pi_{N-1|N} = \mathrm{P}_N.$$

The given strategy allows to synthesize control systems on the basis of principle of distribution. According to this principle estimation procedure of parameters or state variables is carried out separately with calculation of controller parameters.

3. ALGORITHMS OF THE DECISION

Let's consider the linear dynamic system described by the Eq.(1), Eq.(2). The important property of the optimum filter consists in that [2, 6] that remainder terms defined as,

$$y_i = z_i - H_i\hat{x}_{i|i-1},$$

are sequence of a kind of white noise. Thus covariance of remainder term is equal

$$C_0 \overset{\Delta}{=} E\left[y_iy_i^T\right] = HPH^T + R,$$

and autocovariance matrix of process y_i is equal

$$C_j \overset{\Delta}{=} E\left[y_{i+j}y_i^T\right] = H\left[A(I-KH)\right]^{j-1}A\left[PH^T - KC_0\right], \tag{7}$$

at $j = 1,2,3,\ldots$, where K - random gain.

Defining matrix S as

$$S = PH^T - KC_0, \tag{8}$$

The Eq.(7) can be written down in a kind:

$$C_j = H\left[A(I-KH)\right]^{j-1}AS,$$

Matrixes K and S in the Eq.(7) and Eq.(8) have identical dimension $n \times m$. Absolute minimum of function f, defined in a kind

$$f = \frac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{m}s_{ij}^2$$

where, s_{ij} - (i, j) th element of matrix S, is reached at $S = 0$.

For definition of gain factor K which results matrix S in zero, we will use a gradient projection method. At enough small errors in initial data first approximations in gradient methods usually differ from corresponding approximations at exact initial data a little. With increase in number of iterations received approximations can deviate from desired solutions far somehow. In other words, for basic applicability of any iteration method, in particular, gradient, to the decision of ill-posed problems it should generate regularizing family of operators [13-15] in which iteration number is regularization parameter.

Let's write down A. N. Tikhonov's function for a considered problem

$$T_r(k_{pq}) = J(k_{pq}) + \alpha_r\Omega(k_{pq}),\ k_{pq} \in K,$$

where, $\alpha_r > 0$, $r = 1, 2,\ldots$, $\lim_{r\to\infty}\alpha_r = 0$, and function $\Omega(k_{pq}) = \left\|k_{pq}\right\|^2 \big/ 2$ is stabilizer.

As $\Omega(k_{pq}) = \left\|k_{pq}\right\|^2 \big/ 2$ - strongly convex function, then Ω - normal solution exists and it is unique

$$(k_{pq}^* \in K^* = \{k_{pq} : k_{pq} \in K,\ J(k_{pq}) = J_*\},$$
$$J_* = \inf\ J(k_{pq}),\ J_* > -\infty)$$

thus, $\lim_{r\to\infty}\left\|k_{pq}^r - k_{pq}^*\right\| = 0$ and $\left\|v_r - k_{pq}^r\right\| \to 0$ at $r\to\infty$.

Then it is possible to show [13, 15], that sequence $\left\{k_{pq}^r\right\}$ defined by a condition

$$\varsigma_{r+1} = P_K\left(\varsigma_r - \beta_r\left(f_r'\left(\varsigma_r\right) + \alpha_r\varsigma_r\right)\right),$$
$$r = 1,2,\ldots;\ \varsigma_1 \in K, \tag{9}$$

It converges on norm to point $k_{pq}^* \in K^*$ with the minimum norm. Sequences $\{\alpha_r\}$, $\{\beta_r\}$ in Eq.(9) it is possible to choose, for example, in the form of $\alpha_r = r^{-1/3}$, $\beta_r = r^{-1/2}$, $r = 1,2,\ldots$

For the decision of adaptive estimation problem of state vector in the conditions of prior uncertainty covariance matrixes of object noise and disturbances of measurements we will write down expression for update process

$$v_{i+l|i} = z_{i+l} - H\hat{x}_{i+l|i},$$

where, $\hat{x}_{i+l|i} = A_{i+l,i}\hat{x}_i = A_i^l\hat{x}_i$.

Let's consider the following sequence of cross correlation matrixes $M\left(v_{i+j|i}v_{i+1|i}^2\right)$, $j = 2,\ldots,l$. Following methods of optimum dynamic filtration [2, 5, 8] it is possible to show, that

$$M\left(v_{i+j|i}v_{i+1|i}^2\right) = HA_i^{j-1}{}_iP_{i+1|i}H^T,\ j = 2,\ldots,l, \tag{10}$$

where, $P_{i+1|i} = M\left(\tilde{x}_{i+1|i}\tilde{x}^T_{i+1|i}\right).$

The Eq.(10) can be written down in the matrix form

$$Y_v = SP_{i+1|i}H^T \,, \tag{11}$$

where, $Y_v = \begin{bmatrix} M(v_{i+2|i}v^T_{i+1|i}) \\ M(v_{i+3|i}v^T_{i+1|i}) \\ M(v_{i+4|i}v^T_{i+1|i}) \\ \cdots \\ M(v_{i+l|i}v^T_{i+1|i}) \end{bmatrix}, \; S = \begin{bmatrix} H \\ HA_i \\ HA_i^2 \\ \cdots \\ HA_i^{l-2} \end{bmatrix} A_i \,.$

Other ways of matrixes Y_v and S formation are possible also. For synthesis of the adaptive filter in considered statement it is necessary to calculate matrix $P_{i+1|i}H^T$. Accepting more realistic point of view we will suppose, that the right part of the Eq.(11) is set with some error caused by presence of noise of object model and a disturbances of measurements in Eq.(1) and Eq.(2). Thus, instead of Eq.(11) we will consider equation

$$Y_v^{\delta} = SP_{i+1|i}H^T \,, \tag{12}$$

with condition of approximation $\left\| y^{\delta}_{v,j} - y_{v,j} \right\| \le \delta$ for each j (j = 1, 2,…, m) - column number of matrix Y_v^{δ}.

For simplification of the further computations we will copy the Eq.(12) in a kind

$$Y_v^{\delta} = SD_i \tag{13}$$

where, $D_i = P_{i+1|i}H_i^T$.

Let's apply to the decision of the Eq.(13) regularization method. Then

$$d_j^{\alpha} = \left(\alpha I + S^T S\right)^{-1} S^T y^{\delta}_{v,j} \quad (\alpha = r^{-1}),$$

where, $\alpha > 0$ - regularization parameter.

From the computing point of view t iterated variant [15] of regularization method which can be written down in a kind is more convenient:

$$d_{j,r} = \left(I - S^T S g_r\left(S^T S\right)\right) d_{j,0} + g_r\left(S^T S\right) S^T y^{\delta}_{v,j}, \quad j = 1,\ldots,m, \tag{14}$$

where, d_j- j^{th} matrix column D, $g_r\,(S^T S) = (S^T S + \alpha I)^{-1}$ or $g_r(\lambda) = (r^{-1} + \lambda)^{-1}$, $0 \le \lambda < \infty$ - generating function system.

Regularization parameter r in algorithm Eq.(14) is expedient for choosing on size of residual $\left\| Sd_j^r - y^{\delta}_{v,j} \right\|$. At realization of approximation Eq.(14) regularization parameter we will choose proceeding from performance of an inequality of a kind

$$b_1\delta \le \left\| Sd_{j,r} - y^{\delta}_{v,j} \right\| \le b_2\delta \,, \; b_1 > 1 \,, \; b_2 \ge b_1 \,. \tag{15}$$

Thus, if,

$$\left\| Sd_{j,0} - y^{\delta}_{v,j} \right\| \le b_2\delta \tag{16}$$

Assuming r = 0, i.e. for approximate solution of the Eq.(13) we will accept initial approximation $d_{j,0}$.

For an establishment of convergence of approximation Eq.(14) on the basis of rule Eq.(15) of stopping of iterative process let's consider expressions

$$d_{j,r} - d_j^* = \left(I - S^T S g_r\left(S^T S\right)\right)\left(d_{j,0} - d_j^*\right) + g_r\left(S^T S\right) S^T \left(y^{\delta}_{v,j} - y_{v,j}\right), \tag{17}$$

$$Sd_{j,r} - y^{\delta}_{v,j} = S\left(I - S^T S g_r\left(S^T S\right)\right)\left(d_{j,0} - d_j^*\right) - \left(I - S^T S g_r\left(S^T S\right)\right)\left(y^{\delta}_{v,j} - y_{v,j}\right), \tag{18}$$

where, d_j^* – nearest to $d_{j,0}$ solution of Eq.(13).

Thus, if the rule of stopping Eq.(15) at as much as small $\delta > 0$ gives out r = 0, then

$$\left\| Sd_{j,0} - y^{\delta}_{v,j} \right\| \le b_2\delta \tag{19}$$

and in a limit at $\delta \to 0$ it is received

$$Sd_{0,\,r} = y_{v,j} \tag{20}$$

That is, $d_{0,r}$ - solution of Eq.(13). The approach accepted here also appears effective at the decision robust estimation problems of state vector and covariance matrixes of object noise, synthesis regularized algorithms of adaptive filtration on sequence of scalar measurements, and designing of adaptive reduced algorithms of estimation conditions of dynamic systems. It is shown, that at their practical realization effective there are computing circuits simplified regularization and regularized method of quickest descent.

4. PRACTICAL REALIZATION

The regular algorithms of estimation of a condition of dynamic objects of management received above on the basis of concepts of an adaptive filtration found practical application at the solution of problems of synthesis of systems of adaptive management of technological processes of granulation drying of an ammophos pulp and receiving ammonia.

4.1 SYNTHESIS OF SYSTEM OF ADAPTIVE MANAGEMENT BY TECHNOLOGICAL PROCESS GRANULATIONS DRYINGS OF AN AMMOPHOS PULP

In production of complex mineral fertilizers the big share of release is necessary on ammophos, as most agrochemical valuable fertilizer. The sequence of a production cycle in ammophos production finishes process of granulation drying of an ammophos pulp in the device of the granulating drum-dryers (GDD). The device has three zones: drying, granulation and before drying of granules. The pulp of phosphates of ammonium is dispersed by pneumatic nozzles in a drying zone. In the same place by means of the special device the veil from the dried-up particles of a finished product is created. Drops of a pulp cooperate with product particles, increasing their size. Passing from a nozzle torch to a veil, the pulp concentrates at the expense of heat of warm gases, and further there is a final drying of a product [16].

When drying damp ammophos granules, as well as other products, two processes at the same time proceed: moisture evaporation (weight exchange) and heat transfer (heat exchange). Water in ammophos is generally connected with salts capillary forces (hygroscopic moisture). To 0, 5 % of water it is connected in a look crystal hydrates (crystallization moisture) which, as a rule, don't collapse at drying temperatures. Thus, the residual humidity of a product equal of 0, 5 %, corresponds to the contents in it crystallization moisture. In the course of drying ammophos rather fast evaporation of moisture from a surface of a material and its slow moving from inside layers of a material to its surface occurs furnace gases at 600-6500C. This process proceeds until pressure of water vapor in smoke gases doesn't become equal to pressure of saturated steam of water over a dried-up material.

Efficiency of process of granulation drying and physical and chemical properties of granules depend not only from the sizes and a design of dryers granulators, but also on level of automation and possibilities of the automatic monitoring system of parameters of a technological mode [17]. Automation of control, regulation and management of technological processes in ammophos production is dictated by problems of improvement of quality of a finished product, intensification and conducting processes in optimum modes.

A variety of available situations and forms of their influence on object of management, impossibility of obtaining full information on course undivided in time of processes of drying, crystallization and granulation, each of which has the kinetics and revolting influences, point to that circumstance that processes in GDD are characterized by conditions of incomplete information. For increase of efficiency of considered technological process the problem of adaptive stabilization of operating modes of object is one of the main tasks of management.

The purpose of adaptive stabilization is maintenance of a small dynamic error of stabilization and invariable dynamic characteristics of the closed contour irrespective of change of variable parameters of object and indignations. As well as in case of local adaptive regulators, in practice are limited to the requirement of weak dependence of dynamic characteristics from variable parameters of object.

The choice of structure of mathematical model, definition of the basic control variables influencing qualitative index of process, were carried out at a stage of preliminary research of work GDD in a mode of its normal operation. As the basic indicators characterizing process of drying-granulation, following variables were considered:

Processing variables $U = (u_1, u_2, u_3)$, where u_1 - temperature of heat carrier on input GDD; u_2 - pulp discharge; u_3 - discharge recycle;

Output parameters $Y = (y_1, y_2, y_3)$, where y_1 - temperature of spent heat carrier; y_2 - humidity of granules; y_3 - granulometric composition of ammophos;

Perturbation actions $W = (w_1, w_2, w_3)$, where w_1 - moisture content of ammophos pulp; w_2 - granulometric composition of pulp; w_3 - granulometric composition of recycle.

The made formalization of process allows to choose structure of mathematical model in a following kind:

$$x_{i+1} = A_i x_i + F_i x_{i-h} + B_i u_i + w_i, \tag{21}$$

$$y_i = H_i x_i + v_i. \tag{22}$$

Let's suppose, that process of vector of parameters change $\theta^T = [a^T \mid f^T \mid b^T]$ represents Markovian process of kind $\theta_{i+1} = \theta_i + w_i^{\theta}$,

where,

$$a^T = (a_{11}, a_{12}, a_{13}, a_{21}, a_{22}, a_{23}, a_{31}, a_{32}, a_{33}),$$
$$f^T = (f_{11}, f_{12}, f_{13}, f_{21}, f_{22}, f_{23}, f_{31}, f_{32}, f_{33}), \tag{23}$$
$$b^T = (b_{11}, b_{12}, b_{13}, b_{21}, b_{22}, b_{23}, b_{31}, b_{32}, b_{33}),$$

w_i^{θ} - realization of the random function.

Then the process and supervision equations will register in a kind:

$$x_{i+1} = A_i x_i + F_i x_{i-h} + w_i, \tag{24}$$

$$\theta_{i+1} = \theta_i + w_i^{\theta}, \tag{25}$$

$$y_i = H_i x_i + v_i, \tag{26}$$

where, $w_i, w_i^{\theta}, v_i,\ i = 0,1,...$ – not dependent from each other white Gaussian sequences:

$$E[w_i w_l^T] = Q_i^x \,\delta_{il},$$

$$E[w_i^{\theta} w_l^{\theta T}] = Q_i^{\theta} \,\delta_{il},$$

$$E[v_i v_l^T] = R_i \,\delta_{il}.$$

In difference Eq.(24), Eq.(26) management u_i in explicit form is not considered. However management always is considered known (precisely measured) time function. Therefore it can be considered through dependence on discrete time i, as it is meant in expressions Eq.(24), Eq.(26).

For reception and practical use of identifiable models as means for forecasting and object output coordinates control, has been made industrial experiment in the conditions of normal functioning of technological process of granulation-drying of ammophos pulps. In the course of experiment the control was carried out both is continuous, and discretely method of spot test depending on observability of this or that technological parameter.

For working out of mathematical model of considered process the algorithms of identification based on dynamic estimation theory have been used. As the expanded state vector, vector $x^{pT} = [x^T \mid \theta^T]$ has been accepted. The mathematical model establishing quantitative relationship between the basic variable processes, looks like:

$$\begin{bmatrix} x_{1,i+1} \\ x_{2,i+1} \\ x_{3,i+1} \end{bmatrix} = \begin{bmatrix} 0,921 & -0,234 & 0,301 \\ 0,877 & 0,616 & 0,423 \\ 0,753 & 0,214 & -0,175 \end{bmatrix} \cdot \begin{bmatrix} x_{1,i} \\ x_{2,i} \\ x_{3,i} \end{bmatrix} + \begin{bmatrix} 0,254 & -0,321 & 0,911 \\ 0,975 & 0,196 & 0,712 \\ -0,553 & 0,142 & 0,659 \end{bmatrix} \cdot \begin{bmatrix} x_{1,i-h} \\ x_{2,i-h} \\ x_{3,i-h} \end{bmatrix} + \begin{bmatrix} -0,455 & 0,391 & 0,153 \\ 0,322 & 0,686 & 0,174 \\ 0,183 & -0,482 & 0,558 \end{bmatrix} \cdot \begin{bmatrix} u_{1,i} \\ u_{2,i} \\ u_{3,i} \end{bmatrix} + \begin{bmatrix} w_{1,i} \\ w_{2,i} \\ w_{3,i} \end{bmatrix}, \tag{27}$$

$$\begin{bmatrix} y_{1,i} \\ y_{2,i} \\ y_{3,i} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} \cdot \begin{bmatrix} x_{1,i} \\ x_{2,i} \\ x_{3,i} \end{bmatrix} + \begin{bmatrix} v_{1,i} \\ v_{2,i} \\ v_{3,i} \end{bmatrix}. \tag{28}$$

Check of models verification on the basis of the criterion connected with check of assumptions concerning model and based on analysis of leavings properties, has shown, that model Eq.(27)-Eq.(28) sufficiently describes considered process in area of experimentation and can be used at control system engineering. The developed mathematical model of process of granulation-drying ammophos pulps allow to establish proportion between the cores input and output variables, to forecast a process condition at available or chosen managements and to synthesize optimum adaptive control laws of considered process.

Management of considered process of granulation-drying appears rather difficult because of its nonminimum-phase properties with time delay some minutes, long settling time, the big range of moisture content crude pulp fluctuations and immeasurable changes of pulp properties. The problem consists in improvement of control quality at the expense of application of the control computer. We will connect to object (21), (22) regulator

$$u_i = \mathrm{K}_i^T z_i , \qquad (29)$$

where, K = $n\times 2l\text{-}d$ matrix of regulator parameters, $z_i^T = y_i^T\, y_{i-h}^T$

We will assume, that matrixes A, F, B, H depend on a vector of unknown parameters $\xi \in M$, where M - the set defining a class of adaptability of synthesized system. For the decision of a considered problem we will take Lyapunov-Krasovsky functional [1] in a kind

$$V(x_s, \mathrm{k}_s) = x_i^T L_0 x_i + \sum_{i=1}^{m} (\mathrm{k}_i - \mathrm{k}_{0i})^T L_i (\mathrm{k}_i - \mathrm{k}_{0i}) - \gamma \left[\frac{1}{2}\left(x_{i-h}^T x_{i-h} + x_i^T x_i \right) + \sum_{l=1-h}^{-1} x_{i+l}^T x_{i+l} \right],$$

where, L_0, L_i – real symmetric positive definite matrix; K_{0i} – i^{th} column of some matrix K_0, $\gamma > 0$.

Then it is possible to show [18, 19], that system Eq.(21), Eq.(22) will be adaptive in set class M and algorithm of adjustment of parameters of a regulator here in below,

$$\mathrm{k}_{i+1} = \mathrm{k}_i - \mathrm{d}_i^T y_i P_i z_i ,\ i = 1,2,...,m , \qquad (30)$$

where, P_i - arbitrary positive definite matrix; d_i- i^{th} column of matrix D defined by conditions of frequency theorem of stability.

The equation of Kalman filter for a considered problem will become:

$$\hat{x}_{i+1} = A_i \hat{x}_i + F_i\ \hat{x}_{i-h} + B_i u_i + K_i^1 [y_i - \mathrm{K}_i \hat{x}_i - \mathrm{K}_i B_i u_i] - \frac{h}{n}\left[\frac{1}{2}\left(K_{i,-h}^2 [y_{i-h} - \mathrm{K}_{i-h} \hat{x}_{i-h}] + K_{i,0}^2 [y_i - \mathrm{K}_i \hat{x}_i] \right) + \sum_{l=1-h}^{-1} K_{i,l}^2 [y_{i+l} - \mathrm{K}_{i+l} \hat{x}_{i+l}] \right]. \qquad (31)$$

Gain factors K_i^1 and K_i^2 are defined by the equations

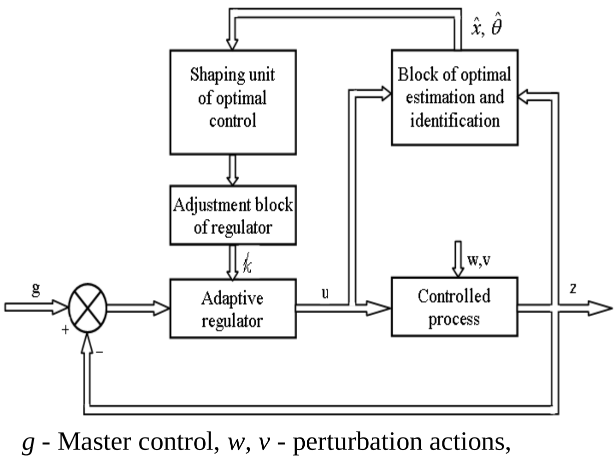
$$K_i^1 = [P_i - P_{i,0}] \mathrm{K}_i^T R_i^{-1}, \quad K_{i,s}^2 = P_{i,s} \mathrm{K}_{i+s}^T R_{i+s}^{-1} . \qquad (32)$$

The equations for covariance matrix of error of estimation will become:

$$\begin{aligned} P_{i+1} &= A_i P_i + P_i A_i^T - P_i \mathrm{N}_i P_i + F_i + P_{i,0} \mathrm{N}_i P_{i,0} \\ &\quad - \frac{h}{n}\left[\frac{1}{2}\left(P_{i,-h} \mathrm{N}_{i,-h} P_{i,-h} + P_{i,0} \mathrm{N}_{i,0} P_{i,0} \right) + \sum_{l=1-h}^{-1} P_{i,l} \mathrm{N}_{i,l} P_{i,l} \right] \\ &\quad + A_i^1 P_{i,-h} + P_{i,-h} A_i^{1T},\ P_0 = P_{i_0}, \\ \frac{\partial P_{i,s}}{\partial t} &= \frac{\partial P_{i,s}}{\partial s} + [A_i - [P_i - P_{i,0}] \mathrm{N}_i] P_{i,s} + A_i^1 P_{t,-h,s} \\ &\quad + \frac{h}{n}\left[\frac{1}{2}\left(P_{i,-h} \mathrm{N}_{i-h} P_{i,-h,s} + P_{i,0} \mathrm{N}_i P_{i,0,s} \right) + \sum_{l=1-h}^{-1} P_{i,l} \mathrm{N}_{i+l} P_{i,l,s} \right],\ P_{i_0} \equiv 0,\ s \in [-h, 0), \\ \frac{\partial P_{i,r,s}}{\partial t} &= \frac{\partial P_{i,r,s}}{\partial r} + \frac{\partial P_{i,r,s}}{\partial s},\ P_{i_0,r,s} \equiv 0, \\ & r, s \in [-h, 0),\ P_{i,r,s} = P_{i,s,r}^T, \\ & \mathrm{N}_i = H_i^T R_i^{-1} H_i . \end{aligned} \qquad (33)$$

On the basis of correlations Eq.(30) – Eq.(33) and developed above synthesis algorithms of adaptive estimation system of state vector it is possible to offer the following variant of an adaptive control system of granulation-drying process evaporated ammophos pulps (Fig.1).

Processes of coordinate and parametrical estimation here are connected very closely. Universality of the presented complex of algorithms is defined by their adaptive properties. Really, all aprioristic information put in a complex at a design stage, is consolidated to structure of mathematical model of operated process, criterion of optimization, structure of sensors and intensity of their noise. All other information turns out in the course of functioning of the complex. It is high level of adaptability and universality. He allows applying the same complex of algorithms to management of the most various processes. Let's notice that the block of adaptive estimation presented on Fig.1 can be allocated in the COMPUTER program or represent separate sub blocks.



g - Master control, w, v - perturbation actions,
u – Control actions, $\hat{\theta}$ - estimations of object parameters, $\hat{x}$ - estimations of object current status,
k - adjustable parameters of regulator,
z – output signal of object

Fig.1. Structure of an adaptive control system Granulation-drying process evaporated ammophos pulps

At management of big system some levels (multidimensional contours) managements can be applied, each of which can be organized as a type complex Fig.1. Let's note that creation of universal algorithms of optimum control opens ample opportunities of automation of management of continuous technological processes by means of application of the standard unified means of creation of industrial control systems.

Practical realization of the offered adaptive control system will allow to stabilize operating practices of process and to raise efficiency of GDD functioning in phosphorous-containing combined fertilizer manufacture.

4.2 SYNTHESIS IT IS ADAPTIVE AN INVARIANT CONTROL SYSTEM OF A COLUMN OF SYNTHESIS OF AMMONIA

Basis of the industry of nitric and difficult fertilizers, and also many other major products of the chemical industry is ammonia. In production of ammonia by one of the most important technological transitions defining both quality of the let-out product, and technological indicators of all production, the column of synthesis of ammonia is [20]. Synthesis of ammonia is, on the one hand, difficult process at the same time warm and mass of an exchange, and with another – technological physical and chemical process at which carrying out initial properties of materials should be not only are kept, but in some cases even are improved.

The following fragment of the technological scheme of production of ammonia is subject to management and control. The fresh nitrogen-hydrogen mix (NHM) in number of 954 m^3/h arrives in a heater where heats up to 480 °C at the expense of condensation of water vapor. Then the part of NHM goes to the internal heat exchanger of a column of synthesis of ammonia for a recuperation of heat of reaction of synthesis and heats up at the expense of heat of the synthesized gas. The quantity of NHM sent to the internal heat exchanger, is regulated by a contour which is maintaining temperature over the first shelf within 510-520 °C. As process of synthesis of ammonia proceeds with heat allocation, for temperature regulation in a column is provided bypass cold gas on the third shelf. The most part of the received gaseous ammonia is condensed in a column of condensation of ammonia, and remained again comes back to a synthesis column. As object of management at automation of process of synthesis of ammonia we will accept a column of synthesis of ammonia together with the internal heat exchanger and a heater of fresh NHM. Efficiency of process of synthesis of ammonia depends on several parameters. As formation of NH3 occurs to considerable reduction of volume, it is necessary to support in a column optimum pressure – 32 MPas. The temperature of process is supported bypass on the third shelf and quantity of NHM sent to the internal heat exchanger. Directly to influence concentration of ammonia in the synthesized gas it is not obviously possible, since it depends on structure of initial NHM and from amount of ammonia in circulating gas [20,21].

The main objective of automatic control of process of synthesis of ammonia is creation of the stable and optimum mode providing the maximum exit of production and trouble-free operation. The process occurring in a column, is connected with allocation of a significant amount of heat, and the slightest changes of regulating influences strongly are reflected in a temperature mode to a column. Specifications of management of a temperature mode of the reactor the very rigid; big static accuracy, fast alignment of temperature, i.e. big speed and considerable dynamic accuracy are required.

As a result of the carried-out industrial experiments it is established that change of extent of opening of a valve on a bypass stream influences temperature both in corresponding, and in underlaying layers, besides, on temperature considerable influence is rendered by concentration of ammonia, inert impurity and a ratio of NHM reagents. In this regard it is possible to consider as the main variables of process the following: operating parameters $u = (u_1,u_2,u_3,u_4)$, where: $u_1 \div u_4$ – extents of opening a valve on bypass streams; target parameters $y = (y_1,y_2,y_3,y_4)$, where, $y_1 \div y_4$ – temperatures in catalyst layers; controllable indignations of $\mu = (\mu_1, \mu_2, \mu_3)$, μ_1 – an expense of initial NHM, μ_2 – a ratio of nitrogen and hydrogen, μ_3 – a consumption of circulating gas; uncontrollable indignations of $w = (w_1,w_2)$ where w_1 – concentration of ammonia, w_2 – concentration of inert gases.

For definition of dynamic characteristics of considered object on the main channels of signaling methods of active experiment were used. On the received experimental dynamic characteristics of the four-half-internal reactor of synthesis of ammonia parametrical identification of transfer functions of the main and cross channels of object by a method of the smallest squares (a step of quantization of T_0 = 10 second) and the difference equations of the first order is carried out.

On channels of action of controllable indignations of $\mu = (\mu_1, \mu_2, \mu_3)$, μ_1 – an expense of initial NHM, μ_2 – a ratio of nitrogen and hydrogen, μ_3 – a consumption of circulating gas and $y_1 \div y_4$ temperatures in the corresponding layers of the catalyst dynamic characteristics were defined on the basis of a correlation method. Researches showed that the received dynamic characteristics on the main channels of signaling and action of controllable indignations can be approximated by aperiodic links in a joint with links of pure delay.

In the synthesized it is adaptive to an invariant control system of a column of synthesis of ammonia as the main digital regulators the digital regulators of the second order realizing digital PID - the regulation law are used. On the basis of known algorithms parameters of the main digital regulators are calculated. Optimization is carried out by criterion of a minimum of an integrated and square-law mistake (ISM) in one-planimetric systems on models of equivalent objects.

For the purpose of the accounting of mutual influence between adjustable parameters of process synthesis of an independent digital control system is carried out. Parameters of discrete transfer functions of jacks of cross communications are calculated.

During computer modeling comparative researches of transients in untied and independent digital control systems are carried out. Modeling is carried out in the presence of external indignations. The results of researches presented by values of ISM and a static mistake (SM) show improvement of criteria of quality (on the first channel indicators remained invariable as there are no cross communications, on the second channel improvement of ISM makes 3, 3%, on the third and fourth channels improvement of ISM makes 0, 15% and 1, 3% respectively).

Minor improvement of quality of management speaks existence of external uncontrollable indignations (concentration of ammonia and inert gases), making negative impact on temperature in catalyst layers.

Development of the system of the management is necessary for improvement of indicators of quality of management, considering influence of indignations. One of options thus is it is adaptive an invariant control system.

For the received structures of transfer functions of jacks of indignations with use of return z-transformation the interrelation of parameters of jacks of indignations from parameters of the main channels and channels of indignations is received.

On Fig.2 the function chart developed is presented is adaptive an invariant control system of a column of synthesis of the ammonia, consisting of the reactor 1, temperature sensors in layers of the catalyst 2-5, an adaptive multichannel regulator (AMR) 6, blocks of identification (BI) 8, estimation of uncontrollable indignations (BEUI) 9, change-over and optimization (BCHO) 10, control of a regulator (BCR) 11, optimization temperatures (BOT) 12.

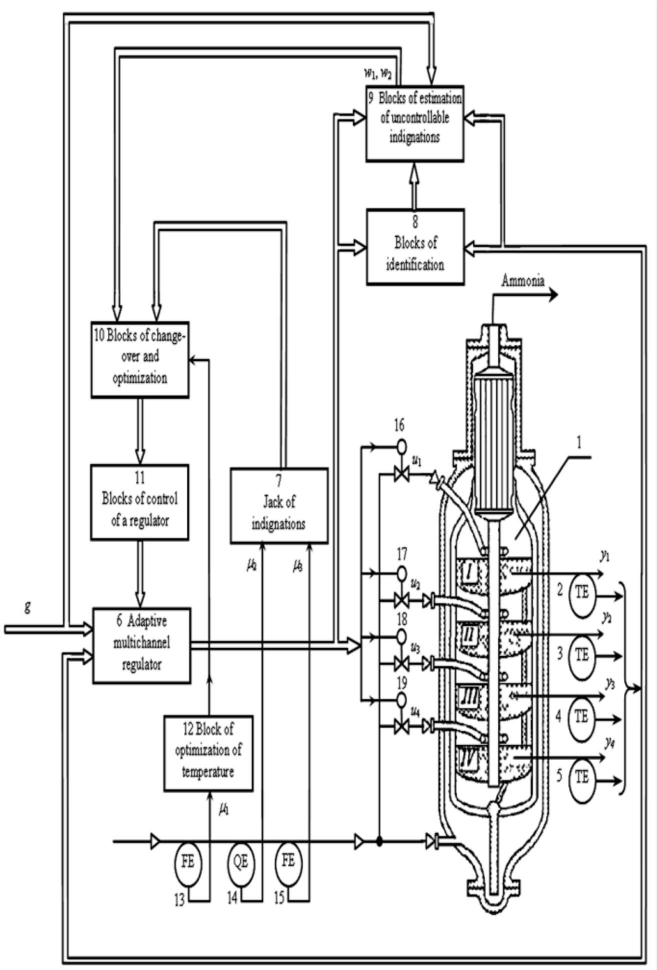


Fig.2. A function chart it is adaptive invariant system managements of a column of synthesis of ammonia

It is adaptive invariant system functions as follows. The current values from sensors of temperature 2-5 arrive in BI 8 and BEUI 9. In these blocks identification of parameters of the main and cross channels and estimation of uncontrollable indignations is carried out. Values of parameters are transferred in BEUI 9. Estimates of object parameters and uncontrollable indignations are transferred in BCHO 10. At the same time with it signals from sensors of concentration ratio of nitrogen and hydrogen 14 and a consumption of circulating gas 15 arrive on the jack of indignations 7, and then in BCHO 10.

Along with it the size of an expense of initial NHM 13 arrives in the BOT 12 where the optimum temperature of reaction of synthesis which provides the maximum exit of ammonia for this value of an expense of ABC is defined. Values of optimum temperatures through BCR 11 arrive as operating impacts on AMR 6. In BCHO 10 taking into account nonlinear dependence of temperature in the first layer of the catalyst from extent of opening of a valve on the basis of piecewise and linear approximation connection of this or that piecewise and band model of direct channels of transfer of influences is made. Thus, BCHO taking into account arrived information calculates AMR 6 settings which in turn regulates valve of bypass streams 16-19.

Thus, application is adaptive invariant system allows to stabilize a technological mode of considered process, to compensate influence of change of parameters of object and uncertain indignations on dynamics of system and to raise quality indicators of management processes.

5. CONCLUSION

In the work regularization algorithms of estimation of condition of dynamic systems in the conditions of aprioristic uncertainty of statistical characteristics of signals and hindrances are offered. Regular iterative algorithms of adaptive estimation of matrix coefficient elements of strengthening of Kalman filter, allowing to adaptive filter for changing hindrance-alarm conditions are developed. Algorithms of steady adaptive estimation algorithms of a condition vector in the aprioristic uncertainty conditions of covariance matrixes of object noise and the measurements hindrances providing a certain roughness of filtration process in relation to changing statistical characteristics of signals information parameters are offered. On the basis of the offered regular algorithms of steady estimation of a state synthesis of system of adaptive management by technological process granulations dryings of an ammophos pulp in production of the granulated fertilizers is carried out and is adaptive an invariant control system of a column of synthesis of the ammonia, allowing to stabilize a technological mode of course of considered processes and to increase efficiency of their functioning.

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