

AUTOMATIC CONTROL SYSTEMS

UDC 681.5(045)

¹O. V. Glushko,
²R. Yu. Tkachev,
³S. S. DenishikSTRUCTURAL PARAMETRIC IDENTIFICATION OF RECYCLE SYSTEMS
FROM REAL IMPULSE RESPONSESDonbass State Technical University, Alchevsk, Ukraine
E-mails: ¹faust.ru@gmail.com, ²tirpitz@ukr.net, ³ssd78@mail.ru

Abstract. Algorithm for structural-parametric identification of plants with recycle loops, containing time-delays both in main channel and in feedback channel, from real-impulse responses is considered in this article.

Keywords: SP-identification; recycle loop; time-delay; continued fraction.

I. INTRODUCTION

Although many works in the field of structural and structural-parametric (SP) identification has been published recently, most of the works on system identification are still based on parametric models (models with predefined structure and unknown parameters) [1], [2].

At present there still not exists a well-developed universally recognized SP-identification method neither for nonlinear dynamical systems nor for linear ones. Such a way a further research in the field of SP-identification is vital for control theory [3], [4].

The problem of structural-parametric identification of plants with time-delays is difficult by itself and it becomes even much more complicated when there are recirculation streams (outlines with positive feedbacks) with time-delays.

The latter are quite common in use, especially in chemical processes when a reactant or processed substance is put back to the previous stage of the process. For instance, recycle processes can take place in crushing machines and recycle columns for sulfuric acid production [5], [6].

Recycle processes are quite difficult to be identified and, as result of this, methods of theoretical modeling are widely used for determination of mathematical models of recycle systems. As for identification approaches, these methods can be divided on two groups: 1) methods with direct experimental impact on recycle loop (most popular ones); 2) passive identification methods [7].

Methods of the first group make it possible to determine dynamical properties of recycle systems from opened loop responses as well as closed loop responses when methods of the second group are applicable in closed loop configuration only. Both approaches are based on recurrent iterative procedures using models with pre-defined structures.

In [8] method of SP-identification of recycle systems from step responses was proposed but in defined situations it is difficult (or even impossible) to apply this method due to the physical restrictions.

Quite often using of impulse responses may solve the problem. Such a way in this article we consider a structural-parametric identification of delay-type objects containing recirculation outlines from impulse responses using discrete-time input and output experimental data.

II. MAIN RESULT

Within the framework of mathematical apparatus of the discrete-time systems the problem of structural-parametric identification comes in fact to the problem of effective power series approximation, where experimental data can be expressed as

$$f(z) = c_0 + c_1 z^{-1} + c_2 z^{-2} + c_3 z^{-3} \dots, \quad (1)$$

where $z = e^{Ts}$, $s = \sigma + j\omega$.

Series (1) can be approximated with continued fractions as it was proposed by V. Ya. Kartashov in [9]. Selection of an order of approximation is the problem to solve at this stage of identification.

Elements of the series (1) are related by recurrent equations determined by the system structure:

$$f(z) = \sum_{i=0}^{\infty} c_i z^{-i} = \frac{Y(z)}{X(z)} = \frac{\sum_{n=0}^{\infty} y(nT) z^{-nT}}{\sum_{n=0}^{\infty} x(nT) z^{-nT}},$$

where $X(z)$ is Z-image of input signal; $Y(z)$ is Z-image of output signal; $y(nT)$ is sequence of output values; $x(nT)$ is sequence of input values.

That makes it possible to exclude Z-image of known input signal from the resulting transfer function of identified object.

General theory of continued fractions conformity with formal Loran series is presented in [10], [11]. The variety of practical methods of representing the power series in a continued fraction form are also given there.

The Rutishauser's method was chosen to be the method of representing analytic functions by continued fractions. This choice is conditioned by several advantages of using Rutishauser method for identification from impulse responses as it was proved in [12].

Rutishauser's method is determined by the formula [10]:

$$\begin{aligned}
 f(z) &\approx \frac{c_0}{1 - \frac{q_1^{(0)}z^{-1}}{1 - \frac{e_1^{(0)}z^{-1}}{1 - \frac{q_2^{(0)}z^{-1}}{1 - \frac{e_2^{(0)}z^{-1}}{\dots}}}}} \\
 &= \frac{c_0}{1 - \frac{q_1^{(0)}z^{-1}}{1 - \frac{e_1^{(0)}z^{-1}}{1 - \frac{q_2^{(0)}z^{-1}}{\dots}}}} \\
 &\quad \vdots \\
 &= \frac{c_0}{1 - \frac{q_{n-1}^{(0)}z^{-1}}{1 - e_{n-1}^{(0)}z^{-1}}} \\
 &= \frac{P(c_0, \{e^{(0)}\}, \{q^{(0)}\})}{Q(\{e^{(0)}\}, \{q^{(0)}\})}, \quad (2)
 \end{aligned}$$

where $e_m^{(n)} \in \mathbb{C}$, $q_m^{(n)} \in \mathbb{C}$, $f(z) \in \hat{\mathbb{C}}$, $\hat{\mathbb{C}} = \mathbb{C} \cup [\infty]$; $\{e_m^{(n)}\}$ and $\{q_m^{(n)}\}$ are sequences determined with following relations: $e_m^{(n)} = q_m^{(n+1)} - q_m^{(n)} + q_{m-1}^{(n+1)}$; $q_{m+1}^{(n)} = \frac{e_m^{(n+1)}}{e_m^{(n)}} q_m^{(n+1)}$; $m = 1, 2, 3 \dots$; $n = 0, 1, 2, 3 \dots$; except $e_0^{(n)} = 0$ and $q_1^{(n)} = \frac{c_{n+1}}{c_n}$.

To determine the most proper order of approximation (which determines structure of the model) methodic proposed in [3] is used: definition of the structure is made by dropping a number of indexes that correspond to values close to zero in the residual fraction numerator.

As it is implied that in (2) $e_m^{(n)} \neq 0$ and $q_m^{(n)} \neq 0$ (for $m = 1, 2, 3 \dots$), the sequence $\{c_n\}$ should be shifted to the first nonzero element and the resulting continued fraction should be multiplied by z^{-d} according to the delay theorem, where d is a shift of the lattice function.

The determination of continued fraction coefficients can be realized by calculation of an identification matrix

$$\begin{matrix}
 0 & a_{1,1} & a_{1,2} & \dots & a_{1,n-2} & a_{1,n-1} \\
 0 & a_{2,1} & a_{2,2} & \dots & a_{2,n-2} & \\
 \dots & \dots & \dots & \dots & \dots & \\
 0 & a_{n-1,1} & & & & \\
 0 & & & & &
 \end{matrix}, \quad (3)$$

where $n -$ is a length of $\{c_n\}$, $a_{i,1} = \frac{c_{i+1}}{c_i}$, and if $j \geq 2$:

$$\begin{aligned}
 a_{i,j} &= \frac{a_{i+1,j-1}}{a_{i,j-1}} a_{i+1,j-2} - \text{for even } j, \text{ and } a_{i,j} = a_{i+1,j-1} \\
 &- a_{i,j-1} + a_{i+1,j-2} - \text{for odd } j.
 \end{aligned}$$

On the basis of the zero-row elements of (3) up to the zero-element the continued fraction is formed. As result of fraction convolution, considering z^{-d} , the discrete-transfer function in fractionally rational form is determined

$$\begin{aligned}
 G(z) &= f_m(z)z^{-d} = \left(\frac{c_0}{1 - \frac{a_{1,1}z^{-1}}{1 - \dots - \frac{a_{1,n}z^{-1}}{1}} \right) z^{-d} \\
 &= \frac{c_0 + c_1z^{-1} + \dots + c_lz^{-k}}{1 + d_1z^{-1} + \dots + d_lz^{-k}} z^{-d},
 \end{aligned}$$

where k is order of the transfer function defined by the order of identification matrix; d is discrete value of the transport time-delay.

On the assumption of the strict equivalency of discrete model to the continuous one, the original continuous transfer function can be retrieved with the inverse Z-transform.

Transient process of system with a recycle loop can be formally divided into three consequent stages: 1) transient process in the open-looped main channel (because of the time-delay in the feedback channel, at this stage system acts as an open-looped one by fact); 2) process caused by the delayed feedback (at this stage system can be considered as open-looped system with nontrivial input signal); 3) process caused by the feedback reaction onto the second stage (at this stage system can be considered as closed-loop system with known input signal and non-zero initial conditions caused by previous stages).

Beginning of each stage of transient process is characterized by structural distortion so that in assumption of quite small sampling time it can be detected with analysis of experimental sequence.

Stages of transient processes can be detected using structural functions alike transient Kolmogorov's structural function.

Basing on the first stage the transfer function of the main loop can be determined. At the same time there is no practical possibility to identify the transfer function of the recycle loop on the values of input and

output sequences of the system while feedback is active because of the difficult nature of the time-delay impact. Based on this, the transfer function of recycle loop should be determined on the output signal of the feedback loop.

As the only observed values are input and output of the system the respective impact for the main channel can be determined from the identified on the first stage transfer function and output sequence of the system, which correspond to the stages two and three.

In order to achieve this, it is necessary to shift from transfer function of main loop to a difference equation in correlation to an input signal

$$x(z) = (y(z)(1 + d_1z^{-1} + \dots + d_kz^{-k}) - x(z)(c_1z^{-1} + \dots + c_kz^{-k})) / c_0.$$

As result the sequence will be found which can be used to determine the sequence of the recycle loop as the system input signal is known.

It is usually impossible to generate a short-time signal which can be assumed to be ideal impulse and therefore real impulses such as rectangular, trapezoidal, sawtooth, triangular at alias are used. In such cases system response should also be decomposed in respect to stages of real-impulse as it was proposed in [12].

When the level of noise and external disturbances is significant, there is a problem of stability of continued fraction approximant so that method described above should be supplemented with characteristic polynomial stability-restrictions.

For characteristic equation:

$$D(z) = a_0 + a_1z + a_2z^2 + \dots + a_nz^n.$$

Stability criterion can be formulated as following. For matrix

$$\begin{matrix} z^0 & z^1 & z^2 & \dots & z^{n-1} & z^n \\ a_0 & a_1 & a_2 & \dots & a_{n-1} & a_n \\ a_n & a_{n-1} & a_{n-2} & \dots & a_1 & a_0 \\ b_0 & b_1 & b_2 & \dots & b_{n-1} & \\ b_{n-1} & b_{n-2} & b_{n-3} & \dots & b_0 & \\ \dots & \dots & \dots & \dots & \dots & \\ s_0 & s_1 & s_2 & s_3 & & \\ s_3 & s_2 & s_1 & s_0 & & \\ r_0 & r_1 & r_2 & & & \end{matrix},$$

where $b_k = \begin{vmatrix} a_0 & a_{n-k} \\ a_n & a_k \end{vmatrix}$, $c_k = \begin{vmatrix} b_0 & b_{n-1-k} \\ b_{n-1} & b_k \end{vmatrix}$,
 $d_k = \begin{vmatrix} c_0 & c_{n-2-k} \\ c_{n-2} & c_k \end{vmatrix}$, \dots $r_0 = \begin{vmatrix} s_0 & s_3 \\ s_3 & s_k \end{vmatrix}$, $r = \begin{vmatrix} s_0 & s_1 \\ s_3 & s_2 \end{vmatrix}$.

Conditions should be met:

$$\begin{cases} |a_0| < a_n \\ |b_0| > |b_{n-1}| \\ |c_0| > |c_{n-2}| \\ |d_0| > |d_{n-3}| \\ \vdots \\ |r_0| > |r_2| \end{cases}$$

Such a way, we have the optimization problem, where minimizing functional can be formulated as

$$J = \sum_{i=0}^n (\bar{c}_i - c_i)^2.$$

Determination of model in a form of continuous transfer function (CTF) can be realized with matched Z-transform [13]:

$$s_i = \frac{\ln(z_i)}{T_s},$$

where s_i are roots of continuous transfer function; z_i are roots of discrete transfer function; T_s is sampling period, s .

Transformation is carried out within the general frequency band, limited by Nyquist frequency according to the Nyquist-Shannon-Kotelnikov sampling theorem. On the basis of matched Z-transform properties the negative roots of z-plane are looped off during the mapping to the s-plane [13]. This fact makes the structural equivalence possible. The parametrical equivalence during the transformation mainly depends on the time-delay sampling error.

In general case the time-delay of continuous object can be represented as: $\tau = d \cdot T - \Delta\tau$, where $\Delta\tau$ is time-delay sampling error, $0 \leq \Delta\tau < T$. When $\Delta\tau \neq 0$ the shift of lattice function is present that causes the zeroes distortion of retrieving CTF. Determination of delay time with assumption of the strict structural equivalency can be realized with the backtab, but it isn't so efficient when zeroes are substantially distorted.

Thereby it is necessary to represent discrete transfer function preliminary divided into the discrete part of data-hold transfer function as a sum of simple fractions

$$G_{in.f}(z) = \frac{G(z)}{G_{d.h.}(z)} = \sum \frac{X_i z}{z - e^{s_i^p T}},$$

where $G_{d.h.}(z)$ is discrete transfer function of data-hold; s_i^p are CTF poles; X_i are numerators of the simple fractions.

When using impulse response, identification of poles can be realized from undisturbed motion of the system and determination of the zeros should be realized with solution of the system of equations formed on the basis of transient process formula:

$$\begin{cases} \sum_{i=0}^{n_1} c_{1,i} e^{-k_{j,i} t_1} + \sum_{i=0}^{n_1} r_{1,i} e^{-k_{j,i} t_1} = y(t_1) \\ \sum_{i=0}^{n_2} c_{2,i} e^{-k_{j,i} t_2} + \sum_{i=0}^{n_2} r_{2,i} e^{-k_{j,i} t_2} = y(t_2) \\ \dots \\ \sum_{i=0}^{n_m} c_{m,i} e^{-k_{j,i} t_m} + \sum_{i=0}^{n_m} r_{m,i} e^{-k_{j,i} t_m} = y(t_m) \end{cases}, \quad (4)$$

where n_j is the order of Laplace transform image of a process at time t_j ; $c_{j,i}$ are unknown numerators of simple fractions that in sum representing image of a process at time t_j ; t_j is time of a sample, s ; $k_{j,i}$ are known poles of a process at time t_j ; $r_{j,i}$ are known coefficients, reflecting the initial state at the beginning of a process at time t_j ; $y(t_j)$ is value of the output coordinate at time t_j .

It should be noted that the time of a sample is supposed to be the time in relation to the beginning of the stage.

Systems of transcendental equations (4) can be solved with numerical methods, while the gain coefficient is determined then by formula

$$k = y_{ss} \frac{\prod |s_p|}{\prod |s_z|}$$

where y_{ss} is steady-state value of the discrete transfer function ($y_{ss} = \lim_{z \rightarrow 1} G(z)$); s_p are poles of continuous transfer function; s_z is initial zero approximations.

III. IDENTIFICATION EXAMPLE

To demonstrate this method of identification consider the identification problem of object with transfer function of main loop

$$W_m(s) = \frac{0.333(s+1.5)}{(s+0.5)(s+1)} e^{-13.7s}$$

And the transfer function of the recycle loop

$$W_r(s) = \frac{0.3}{(s+1.2)} e^{-4.6s}$$

The block scheme of the system is represented in Fig. 1.

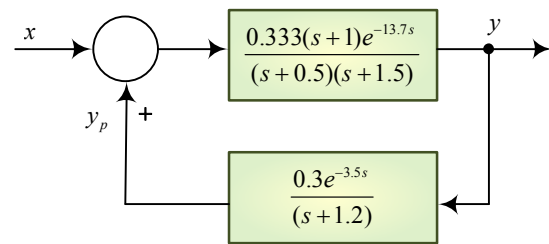


Fig. 1. Block scheme of the identified system: x -input impact; y -output signal of the system; y_p is output signal of the recycle loop

Input signal is a real trapezoidal impulse defined by formula:

$$y_{in}(t) = 2t(1 - \sigma(t - 0.5)) + \sigma(t - 0.5) - \sigma(t - 1) - 2t(\sigma(t - 1) - \sigma(t - 1.5)),$$

where $\sigma(t)$ is Heaviside step function.

Analog-to-digital converter sampling period $T = 0.1s$.

We suppose that there is only measurement noise – white noise with amplitude 0.015.

Scheme used for modeling is represented in Fig. 2.

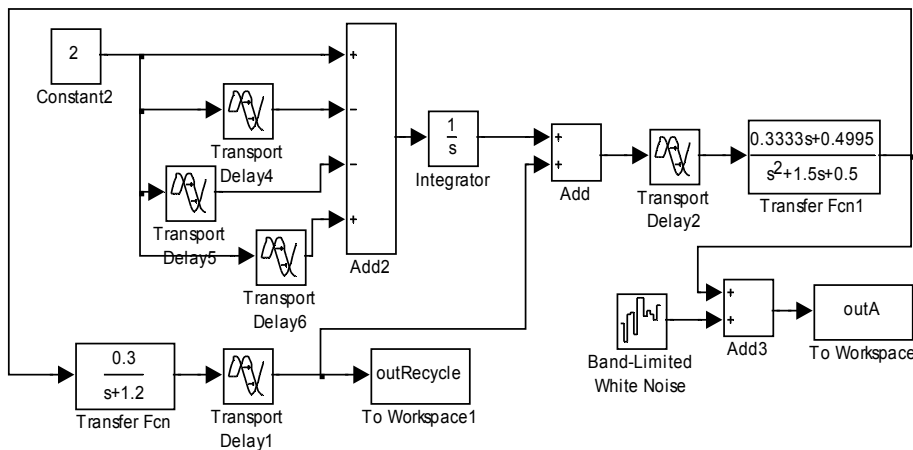


Fig. 2. Scheme used for modeling

The downsampled (to $T = 0.5s$) sequence of system response output values: $y(13.5) = -0.0095$; $y(14) = 0.0268$; $y(14.5) = 0.1496$; $y(15) = 0.2799$; $y(15.5) = 0.3076$; $y(16) = 0.2664$; $y(16.5) = 0.2173$; $y(17) = 0.1821$; $y(17.5) = 0.1587$; $y(18) = 0.1289$; $y(18.5) = 0.0633$; $y(19) = 0.0785$; $y(19.5) = 0.0602$; $y(20) = 0.0658$; $y(20.5) = 0.051$; $y(21) = 0.0572$; $y(21.5) = 0.0243$; $y(22) = 0.0359$; $y(22.5) = 0.0390$; $y(23) = 0.0404$; $y(23.5) = 0.0352$; $y(24) = 0.0327$; $y(24.5) = 0.0249$; $y(25) = 0.0267$; $y(25.5) = 0.0163$; $y(26) = 0.0235$; $y(26.5) = 0.0069$; $y(27) = 0.0280$; $y(27.5) = 0.0272$; $y(28) = 0.0239$; $y(28.5) = 0.031$; $y(29) = 0.0228$; $y(29.5) = 0.0167$; $y(30) = 0.0192 \dots$

The experimental process in presence of measurement noise is represented in Fig. 3.

Using structural function we can find extremums of structural disturbances that correspond to changes in input-signal (stages of recycle process).

From undisturbed motion that corresponds to the first stage of transient process we can determine poles of main-loop transfer function.

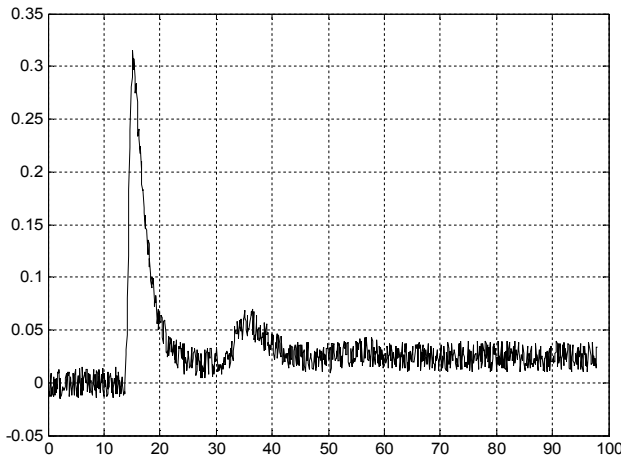


Fig. 3. Experimental impulse response

Identification matrix formed using downsampled to $T = 2s$ output sequence (using downsampling is necessary to increase differences between identification matrix coefficients and to decrease impact of disturbances on the transfer function retrieving accuracy) corresponding to time-frame from 20s to 30s:

$$\begin{matrix} 0 & 0.5105 & -0.0241 & -5.4953 & 7.6712 & -0.9093 & -2.1412 \\ 0 & 0.4864 & 0.2722 & 1.9037 & -3.6641 & 0.6136 & \\ 0 & 0.7586 & 0.6831 & -2.4435 & 0.9202 & & \\ 0 & 1.4416 & -1.1578 & -0.3655 & & & \\ 0 & 0.2839 & 1.4907 & & & & \\ 0 & 1.7746 & & & & & \\ 0 & & & & & & \end{matrix}$$

That leads to unstable transfer function:

$$f(z) = \frac{0.1289z(z^2 - 1.243z + 4.834)}{(z - 0.5277)(z^2 - 1.225z + 4.834)}$$

After iterative correction the stable matrix is formed:

$$\begin{matrix} 0 & 0.4809 & 0.0847 & 0.9544 & -0.1252 & 0.1085 & 0 \\ 0 & 0.5656 & 0.1429 & 0.6862 & -0.0198 & 0.1283 & \\ 0 & 0.7085 & 0.1384 & 0.5280 & -0.0048 & & \\ 0 & 0.8470 & 0.0863 & 0.4369 & & & \\ 0 & 0.9333 & 0.0404 & & & & \\ 0 & 0.9736 & & & & & \\ 0 & & & & & & \end{matrix}$$

Which gives a discrete transfer function:

$$f(z) = \frac{0.12476z(z - 0.9101)(z - 0.1122)}{(z - 1)(z - 0.3679)(z - 0.1353)}$$

Inverse Z-transform gives us

$$f(z) = \frac{0.17683(s + 0.04708)(s + 1.094)}{(s + 1)(s + 0.5)}$$

Then zeroes of continuous transfer function of the model can be represented as

$$F(s) = \frac{N_1s^2 + N_2s + N_3}{(s + 1)(s + 0.5)} e^{\tau}$$

Using a-priori knowledge of the input signal we can form a system of equations to retrieve zeroes of transfer function. As it was shown in [14] transcendental equations for trapezoidal impulse and model of 2nd order can be written as

$$\begin{cases} 2r_2 + 4r_3 - 2r_2e^{d_\tau T_s - t_1} e^{\tau_e} - 4r_3e^{0.5(d_\tau T_s - t_1)} e^{0.5\tau_e} + 2r_1(t_1 - d_\tau T_s - \tau_e) = y_1; \\ r_1 + (r_2 - l_1 + v_1)e^{-t_2} e^{\tau_e} + (r_3 + l_2 - v_2)e^{-0.5t_2} e^{0.5\tau_e} = y_2; \\ r_1 + (r_2 - l_1 + v_1)e^{-t_3} e^{\tau_e} + (r_3 + l_2 - v_2)e^{-0.5t_3} e^{0.5\tau_e} = y_3; \\ r_1 + (r_2 - l_1 + v_1)e^{-t_4} e^{\tau_e} + (r_3 + l_2 - v_2)e^{-0.5t_4} e^{0.5\tau_e} = y_4; \\ l_1 = 5r_1 + 3.2131r_2 + 4r_3; \\ l_2 = 6r_1 + 4r_2 + 4.8848r_3; \\ v_1 = 2r_1 + r_2 + 2r_3; \\ v_2 = 6r_1 + 4r_2 + 5r_3, \end{cases}$$

where $N_1 = r_1 + r_2 + r_3$; $N_2 = 1.5r_1 + 0.5r_2 + r_3$; $N_3 = 0.5r_1$; $r_1 + r_2 + r_3$ are unknown coefficients that can be determined by solution of the following system of transcendental equations: $\tau = d_\tau T_s + \tau_e$ is unknown time-delay; τ_e is time-delay sampling error

($0 \leq \tau_e < T_s$); d_τ is shift of the lattice function to the first nonzero element.

Let's select $t_1 = 13.7s$ (from the beginning of the process) to be equal to 0s in our reference frame; then in respect to t_1 we take $t_2 = 0.2s$; $t_3 = 0.4s$; $t_4 = 0.5s$; (t_2, t_3, t_4 is time from beginning of the second stage).

Corresponding values of output coordinate:

$$y_1 = 0.00043; y_2 = 0.1129; y_3 = 0.1687; y_4 = 0.1967.$$

The solution of the system of transcendental equations gives us:

$$W_m(s) = \frac{0.334s + 0.499}{(s+1)(s+0.5)} e^{-13.7s}.$$

Thus, transfer function of the main loop was retrieved with a high accuracy.

The difference equation for the main loop for the sample period $T = 0.2s$, resolved for the output impact

$$x(k) = (y(k) - 1.856y(k-1) + 0.8607y(k-2) - 0.03327x(k-1) + 0.002864x(k-2)).$$

The solution of this difference equation considering known values of the output and input signal before the second stage (single step impact) gives us the following discrete sequence of input impact as for the feedback to main loop:

$$x(18) = 0.0004; x(18,5) = 0,0008; x(19) = 0,0127; x(19,5) = 0,0361; x(20) = -0,0536; x(20,5) = 0,0594; x(21) = 0,0582; x(21,5) = 0,0534; x(22) = 0,0472; x(22,5) = 0,0407; x(23) = 0,0345; x(23,5) = 0,291\dots$$

In such a way for the identification of the recycle loop the output sequence of system values will be used as input sequence in respect to the main loop.

Stable identification matrix for recycle loop:

$$\begin{array}{cccccc} 0 & 1.8868 & -0.4700 & 0.4700 & -0.0001 & \\ 0 & 1.4169 & -0.1559 & 0.6260 & & \\ 0 & 1.2610 & -0.0774 & & & \\ 0 & 1.1835 & & & & \\ 0 & & & & & \end{array}$$

Discrete transfer function is

$$f(z) = \frac{0.02827z}{(z - 0.8869)}.$$

Continuous transfer function of recycle loop:

$$W_r(s) = \frac{0.299s}{(s+1.01)} e^{-4.6}.$$

IV. SUMMARY

New approach to identification of recycle systems from real impulse responses was proposed. The method of identification allows to determine model's structure as well as model's parameters and provides high accuracy of approximation.

Efficiency of proposed method was demonstrated with illustrative example.

Proposed method involves iterative procedure utilizing numerical methods, and as result of this it is difficult to apply this method for real-time identification. Other disadvantage of the method is that iterative procedures cost much CPU-time that makes this method impossible to be used for identification of models of high order.

As for future research this method should be generalized for MIMO-systems with multiple recycle loops and arbitrary input signals.

REFERENCES

- [1] Ljung, L. System identification – theory for the user. 2nd ed. New Jersey: PTR Prentice Hall, Upper Saddle River, 1999. 609 p.
- [2] Ljung, L.; Söderström, T. Theory and practice of recursive identification. Cambridge, Massachusetts, London: MIT Press, 1987. 541 p.
- [3] Karabutov, N. N. Structural identification: Analysis of dynamical structures. Moscow. Moscow state industrial university publishing, 2008. 160 p. (in Russian).
- [4] Nikulchev, E. V. Identification of dynamic systems based on symmetry of reconstructed attractors. Moscow. Moscow state university of printing arts, 2010. 100 p. (in Russian).
- [5] Uteush, Z. V.; Uteush, E. V. Crushing machines control. Moscow. Mechanical engineering publishing, 1973. 280 p (in Russian).
- [6] Amelin, A. G.; Yashke, E. V. Sulfuric acid production. 2nd ed. Moscow. Higher school publishing, 1980. 245 p (in Russian).
- [7] Lvova, E. I.; Mishlyaev, L. P. Principles and algorithms of identification of industrial plants. Moscow, 26-30 january 2009, SICPRO'09 pp. 289–299.
- [8] Glushko, O. V. “Structural-parametric Identification of Recycle Systems.” *Preprints of 14th International Olympiad on Automatic Control* (Baltic Olympiad). Saint-Petersburg: National Research University of Information Technologies, Mechanics and Optics Saint Petersburg State University, 2011. pp. 129–133.
- [9] Kartashov, V. Ya. “Is the equivalence of discrete models possible?” *Promichlennye sistemy i kontrolleri*. 2006. no. 8. pp. 40–44. (in Russian).

[10] Baker, G. A.; Graves-Morris, P. Pade approximants. London. Addison-Wesley publishing, 1981. – 502 p.

[11] Jones, W. B.; Thron, W. J. Continued fractions: Analytic theory and applications. London. Addison-Wesley publishing, 1980. 414 p.

[12] Glushko, O. V.; Denishik, S. S.; Tkachov, R. Yu. “Solution of real life structural-parametric identification problems using continued fractions.”

2013. *Proceedings of “Tarapov Readings 2013”*, Kharkov. pp. 79–80.

[13] Kuo, B. Digital control systems. London. Oxford University Press, 1992. 448 p.

[14] Tkachev, R. Yu.; Glushko, O. V. On structural-parametric identification of time-delay systems from real impulse response. Kharkov (to be printed).

Received 04 December 2013

Glushko Oleg. Ph. D. Student.

Education: Donbass State Technical University, Alchevsk, Ukraine (2012).

Research interests: system identification, digital control systems

Publications: 13.

E-mail: faust.ru@gmail.com

Tkachev Roman. Cand. of Sci.

Education: Donbass mining-metallurgical institute, Alchevsk, Ukraine (2000).

Research interests: systems and process control, system identification, automatic control of industrial processes

Publications: 46.

E-mail: tirpitz@ukr.net

Denishik Sergey. Cand. of Sci.

Education: Kharkov institute of Radio Electronics, Kharkov, Ukraine (1977).

Research interests: laser location systems, control systems and digital signal processing.

Publications: 34.

E-mail: ssd78@mail.ru

О. В. Глушко, Р. Ю. Ткачов, С. С. Денішкі. Структурно-параметрична ідентифікація систем з рециркуляцією на базі реальних імпульсних характеристик

Розглянуто алгоритм структурно-параметричної ідентифікації систем з каналами рециркуляції, що містять затримки за часом, як в основному каналі, так і в каналах зворотного зв'язку, на базі реальних імпульсних характеристик.

Ключові слова: структурно-параметрична ідентифікація; система з рециркуляцією; узгоджене Z-перетворення; затримка по часу; ланцюговий дріб.

Глушко Олег Володимирович. аспірант.

Освіта: Донбаський державний технічний університет, Алчевськ, Україна (2012).

Напрямок наукової діяльності: ідентифікація систем управління, цифрові системи управління

Кількість публікації: 13.

E-mail: faust.ru@gmail.com

Ткачов Роман Юрійович. Кандидат технічних наук.

Освіта: Донбаський гірничо-металургійний інститут, Алчевськ, Україна (2000).

Напрямок наукової діяльності: системи і процеси управління, ідентифікація, автоматизація систем управління технологічними процесами.

Кількість публікації: 46.

E-mail: tirpitz@ukr.net

Денішкі Сергій Сергійович. Кандидат технічних наук.

Освіта: Харківський інститут радіоелектроніки, Харків, Україна (1977).

Напрямок наукової діяльності: лазерно-локаційні станції, системи управління та цифрова обробка інформації.

Кількість публікації: 34.

E-mail: ssd78@mail.ru

О. В. Глушко, Р. Ю. Ткачев, С. С. Денищик. Структурно-параметрическая идентификация систем с рециклом на основе реальных импульсных характеристик

Рассмотрен алгоритм структурно-параметрической идентификации систем с рециклом, содержащих задержки по времени, как в основном канале так и в каналах обратной связи, на базе реальных импульсных характеристик.

Ключевые слова: структурно-параметрическая идентификация; система с рециклом; согласованное Z-преобразование; задержка по времени; цепная дробь.

Глушко Олег Владимирович. Аспирант.

Образование: Донбасский государственный технический университет, Алчевск, Украина (2012).

Направление научной деятельности: идентификация, цифровые системы управления.

Количество публикаций: 13.

E-mail: faust.ru@gmail.com

Ткачев Роман Юрьевич. Кандидат технических наук.

Образование: Донбасский горно-металлургический институт, Алчевск, Украина (2000).

Направление научной деятельности: системы и процессы управления, идентификация, автоматизация систем управления технологическими процессами.

Количество публикаций: 46.

E-mail: tirpitz@ukr.net

Денищик Сергей Сергеевич. Кандидат технических наук.

Образование: Харьковский институт радиозлектроники, Харьков, Украина (1977).

Направление научной деятельности: лазерно-локационные станции, системы управления и цифровая обработка информации.

Количество публикаций: 34.

E-mail: ssd78@mail.ru