Optimal Digital Control System of Drying Apparatus

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Abstract

This article discusses the questions of selecting the quantization period of continuous control system, it determines the quality of control system. The task of optimal control is assigned for drying apparatus, which is decided by means of discrete optimal state observer. Mathematical model and structural scheme of the digital double-channel system for drying apparatus are worked out.

Stability margin of system is estimated by magnitude of oscillating quality. The quality indices of double channel automatic control system (ACS) with optimal discrete regulator for the various quantization periods are given in table 1 and they are plotted corresponding to transient characteristics.

Keywords: discrete system, Kalman filter, quantization, quantization period, quadratic regulator

Introduction

For the development of market economy the essential importance is placed on the increase of technical-economic efficiency indices of priority spheres and hence, the improvement of product quality on the basis of planning and implementation of automatic control systems (ACS) with the use of contemporary micro processor controllers and computer technique.

In many industrial enterprises various type of drying apparatus are widely used, in which accurate, effective, optimal realization of technological process has a particular importance for world market with a focus on product quality increase. Product quality on drying apparatus outputs is determined by the value of residual moisture content.

Soft and hardware of drying facilities existing until now cannot provide optimum realization of technical process – minimum specific expenses of power and maximum productivity, maintenance residual moisture content of material on standard level. With this reason, it is relevant to develop an optimal digital automatic control system of drying apparatus.

The goal of this article is to work out the digital optimal control system of drying process by using modern computer technologies.

Selecting Quantization Period of Digital ACS

In digital control systems, control action is developed only in discrete time moment $\tau_K,\ K = 0,\pm1,\pm2,...$, which is called a quantization moment. Usually quantization occurs in equal time interval, that is

$$, \quad \tau = KT_0, \quad K = 0,\pm1,\pm2,... \tag{1}$$

As is known T_0 - quantization period presents one of the main parameter of determining the quality of digital system. We can show that when $T_0 \to 0$, the dynamic characteristics of digital system varies according to its various continuous prototype model. With this, selecting very little quantization period perhaps always will not enhance the improvement of regulation quality. Actually normal functioning of closed system is possible with only one condition, when amplitude of disturbing action in the frequency interval is unimportantly higher than any ω_m frequency. Thus, if we consider that digital system must produce $0 \le \omega \le \omega_m$ in the frequency interval between actions of the continuous system, then according to Kotelnikov-Shenon's theory the quantization period must be selected from the following correlation (Izerman R., 1984):

$$T_0 \le \pi / \omega_m \ . \tag{2}$$

For double channel continuous state-variable ACS, the magnitude is determined from corresponding system of the amplitude-phase frequency characteristic (ω_m determines as the least frequency while the characteristic of amplitude-phase frequency cross the unit circle radius with center to point $(-1;\ j0)$)), which must not exceed 0,5 rad/sec. Estimating of quantization period according to (2) is 6,2 sec. For realizing, a double channel state–variable ACS additionally appears the task of selecting quantization period while the required indices of stability and the quality of digital system are achieved with minimal expenses (Bardavelidze Kh., Bardavelidze A., 2011).

Task of Optimal Control for Drying Apparatus

The task of optimal control for drying apparatus is stated in finding of the control principle which occurs in achieving minimum integral quadratic criterion of determining control quality,

$$J = \int_0^\infty (X^T Q X + U^T R U)^2 \, d\tau, \tag{3}$$

where Q and R are the matrixes of weighting coefficients (Izerman R., 1984).

The direct measuring of all parameters of drying process is impossible, therefore the optimal controller maintains the following form:

$$U = -K^T X = -[K_1, K_2, \dots, K_n]X, \tag{4}$$

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where K is a constant matrix of regulator gain coefficient and it is determined with the following coefficients:

$$K = PB^T R^{-1}, \tag{5}$$

where P is a symmetric quadratic matrix and it presents

$$A^T P + PA - PBB^T PR^{-T} + Q = 0, \tag{6}$$

solution of non-linear matrix equation of Riccati. Although, in this case instead of input signal we use the estimating of $\overline{X}$,which is building by using of optimal filter.

Optimal solution of the state observer task represents Kalman permanent filter:

$$\acute{\overline{X}} = A\overline{X} + BU - L(Y - C\overline{X}), \tag{7}$$

where $\overline{X}$ - is a state vector (output of filter), L – is a constant matrix of gain factor:

$$L = (PH^T + \sigma^{-2} I)\ , \tag{8}$$

where P is a solution of algebraic equation Riccati (Astrom K.J & Wittenmark B., 1984)

$$(A - \sigma^{-1}H)P + P(A - \sigma^{-1}H)^T - \sigma^2 PH^T HP = 0\ . \tag{9}$$

Structure of optimal observer presented in *Fig. 1*. Optimal observer integrates Kalman filter and drying apparatus: it uses U – input and Y – results of measurement, in order to calculate variable vector of $\overline{X}$ state output.

In paper, Riccati equation is programmed and solved by the use of integrated applying program packet MatLab "which is a leader among the standard program used for mathematical and engineering calculations".

Structural Scheme of Double Channel Digital ACS

Investigating the dynamics of digital ACS for drying apparatus based on impulse theory (Dorf R., Bishop R., 2002). In Fig.1 is given a structural scheme, which is used for the analyzes of digital dynamic system of drying apparatus.

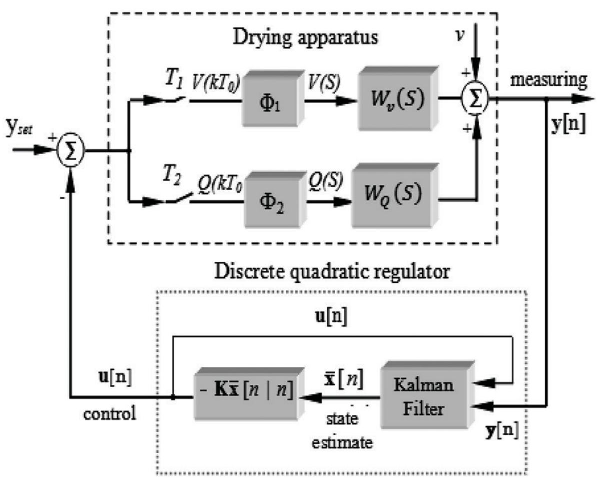

Figure 1: *Structural scheme of double channel digital ACS.*

In the scheme $W_\upsilon(S)$ and $W_Q(S)$ are the transient functions of object, respectively speed and thermal channel; T_1, T_2 - are the devices of signal quantization; Φ_1 , Φ_2 - are the data-hold devices of zero-order, which transforms the input impulse $x[kT_0]$ signal, only for the quantization moment determined in-(1), to impulse subsequence that determined for each moment $y(\tau)$, as

$$y(\tau) = x(kT_0), \quad kT_0 \le \tau \le (k+1)T_0\,.$$

Defining the Transient Function of Double Channel ACS

In theory of control, system for describing object's dynamics uses impulse weighting and transient functions. Impulse transient functions for the continuous part of given system (drying apparatus with fixing devices - Φ_1 , Φ_2) are determined by the following formulas (Bardavelidze Kh., Bardavelidze A.,

$$W_1^*(Z) = \frac{z-1}{z} Z\{g_1(\tau)\},\ \ W_2^*(Z) = \frac{z-1}{z} Z\{g_2(\tau)\}, \tag{10}$$

where $W_1^*(Z)$, $W_2^*(Z)$ are the impulse transient functions of object with speed and thermal channel, $Z\{g(\tau)\}$ -is a time function transformation:

$$Z\{f(\tau)\} = \sum_{k=0}^{\infty} f[kT_0]Z^{-k},$$

but $g_1(\tau)\,, g_2(\tau)$ are the inverse Laplace transform, respectively from $W_{1\upsilon}(S)/S$ and $W_{2\upsilon}(S)/S$ is possible to recieve (Bardavelidze Kh., Bardavelidze A., 2011):

$$S^{-1}W_\upsilon(S) = K_\upsilon[S(T_{1\upsilon}S+1)(T_{2\upsilon}S+1)]^{-1}e^{-\tau_\upsilon S},$$

$$S^{-1}W_Q(S) = K_Q[S(T_Q S+1)]^{-1}e^{-\tau_Q S}\,. \tag{11}$$

By means of (11) could receive $W_{\upsilon Q}(Z)$ transient function of open double channel discrete system:

$$W_{\upsilon Q}(Z) = \frac{(z+8{,}17)(z-1{,}94)(z+0{,}9702)(z-0{,}0997)(z^2+1{,}347z+0{,}4757)}{(z+0{,}971)(z+0{,}7724)(z+0{,}3363)\ (z^2+0{,}1484z+0{,}02422)(z^2+1{,}347z+0{,}4752)}. \tag{12}$$

It is known that for determining quantization time period, it is better to have an immeasurable magnitude, which has a physical gist for oscillating systems and has been connected to an oscillating period, but for non-oscillating systems - to time constant of transient response. We'll determine N_r as the number of quantization period relative to the time of transient response.

$$N_r = T_r / T_0\,,$$

where T_r – is a constant time of transient response, but lower level for this magnitude is given by Shenon's theory. As the length of quantization interval selected from behavior of closed-loop system, so we are using empirical rule and Nr we are selecting in limitation (Izerman R., 1984).

The constant time of transient response has been taken with an optimal regulator from the transient characteristic of double channel state-variable ACS, T_r=13,8 sec. For various values of N_r and T_r have been plotted the transient characteristics of double-channel state variable ACS with discrete quadratic-regulator (*Fig. 2*). Accepted results are presented in table 1. ACS was verified to the absolute and relative stability for each quantization period. The stability margin is estimated by oscillating quality magnitude of discrete system. So for estimating of oscillating quality M^* is sufficient to investigate frequency interval $0 < \omega \le \pi / T_0$, which value is determined as

$$M^* = \frac{|\Phi^*(j\pi/T_0)|}{\min|1+\Phi^*(j\omega)|}, \quad 0<\omega\le\pi/T_0. \qquad (13)$$

The stability margin is considered sufficiently, if $M^* \le 1{,}4$. By calculated result is accepted for the examined double-channel state-variable ACS, stability margin as in continuous systems also in discrete system does not transcend the value - $M^* \le 1{,}4$, for different quantization period.

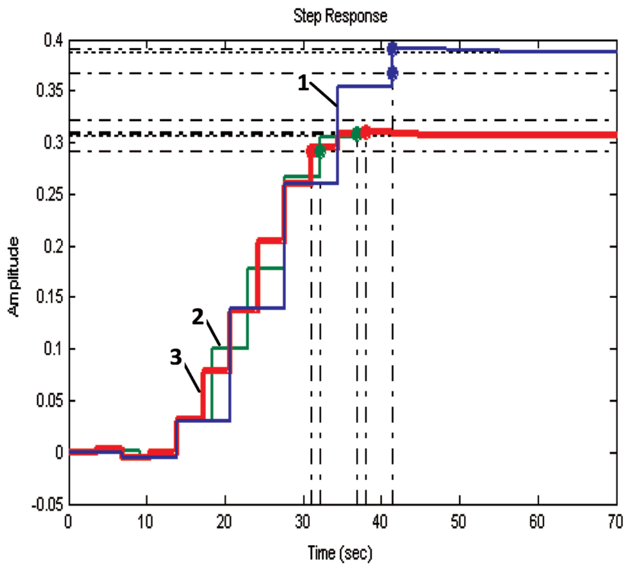

Figure. 2 Transient characteristics of double channel state-variable ACS with optimal discrete quadratic regulator, when 1. T0=6,9; 2. T0=4,6; 3. T0=3,45.

Quantization number in during one period, N_r	Quantization period, T_0	control time, T_s, sec	Overshoot, σ, %
1	6,9	41,4	0,994
2	4,6	32,2	0,43
3	3,45	31,1	1,1

Table 1: *Quality indices of double-channel ACS with discrete regulator*

In *Fig.2*, the third characteristic presents the discrete equivalent of the double channel state variable ACS, because their quality indices conform to each other. It follows that in future for controlling of digital drying apparatus, during the software design, is recommended to take as quantization period 3, 45 sec.

Conclusion

• The discrete mathematical model of drying apparatus is developed in the paper.

• Worked out the discrete linear-quadratic optimal regulator of double channel automatic control system (ACS) by using Kalman's filter in feedback of state variables.

• Developed the digital discrete ACS of double channel.

• Worked out practical recommendations for selecting the quantization time period of system and for parameters setting.

• Analysis showed us that among standard program means is leading integrated applying program packet MatLab, which was used for programming and solving Riccati equation.

• So using the optimal observer, which contains Kalman's filter, importantly improves the transient characteristic of controlling drying apparatus.

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