Synthetic Methodology of Digital Control Systems of Road-Building Machine with a Hydraulic Drive

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***Abstract*— There is considering methodology of digital controllers synthesis of control system of road building machine with electrohydraulic actuator, based on synthetic methodology of system digital part of by continuous prototype and expert approach.**

Keywords*— *road-building machine; electrohydraulic gear; digital control system; controllers design; nonlinear control

I. INTODUCTION

Synthetic methodology of linear control systems regulators been thoroughly studied. In real automatic control systems (ACS) of road-building machines (DPM), hydraulic gears (HG) with signs of non-linearity are used as actuator mechanisms: limiting the power capabilities of the pump set, which leads to non-linearity of the "limiting" type of output signals.

Road-building machines as control objects are mobile machines and usually have electrohydraulic gears of the main mechanisms and are characterized as dynamic systems. To automate the road-building machines, centralized and decentralized microprocessor control systems are used.

The synthesis tasks of nonlinear control systems based on frequency and modal methods are considered in studies [1, 2]. Analysis and synthesis methods of discrete control systems for dynamic objects are considered in many scientific works [3 - 7, etc.].

In the study [8], there are three possible options for designing digital control systems. The method of synthesis of the digital part of the system by a continuous prototype [9] is used to synthesize regulators of real control systems in the applied field - the re-equipment of a continuous controller.

Continuous variables are useful for analysis and synthesis of PID regulators [10]. The technical implementation of a regulator based on a controller or an on-board computer that processes variables derived from analog signals after discrete time sampling and amplitude quantization implies a transition to a discrete form of equations.

When designing an ACS with sufficient ADC/ DAC digits, the amplitude quantization can be neglected, if the error accumulation is correctly estimated and discrete time sampling must be taken into account [11]. In this case, the systems can be regarded as impulse, for which there is a well-developed theoretical apparatus [12].

II. MATHEMATICAL STATEMENT

Determining the sampling time is an actual task. Modern scientific works are devoted to this task [13, 14, etc.]. The theoretical basis for all digital processing, storage and transmission of signals is Kotelnikov's theorem [11, 15, 16, 17].

To ensure an accurate reconstruction, a continuous signal with a spectrum limited by the maximum frequency from a sequence of its discrete values, it is necessary that the amplitude quantization satisfy the condition

$$\omega_0 \geq 2\,\omega_{\max}.$$

Then, for the quantization step for T_0, taking into account the equation $\omega_0 = 2\pi / T_0$ the condition should be satisfied

$$T_0 \leq \frac{\pi}{\omega_{\max}}. \quad (1)$$

Condition (1) is the result of the interruption theorem formulated by Shannon (in Russian literature Kotelnikov).

It should be noted that in automatic control systems or transmission of information continuous signals with restricted spectrum are not encountered in practice. Nevertheless, in the theory of digital control, the Shannon frequency

$$\omega_{Sh} = \omega_0 / 2 = \pi / \mathrm{T}_0,$$

plays the role of a kind of reference constant. It determines the passband of the discrete system [16]. It should be noted that Kotelnikov's theorem in practical problems is never satisfied because of the limited time interval for signal processing [18].

There are known recommendations on sampling time purpose depending on the physical nature of the controlled processes and the features of the system. In the practice of control systems implementation, the following rule has become widespread: the quantization frequency must be an order of magnitude larger than the band of essential frequencies of the object [19].

In the work [14] there is proposed determination the range of sampling time using formula

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$$T_0 \le \frac{T_d}{4 \div 10},$$

where, T_d – time constant of controller differentiation.

In the publication [20], the rational choice of the sampling frequency for closed loop control system is made on the basis of the passband width or from the time of the system overclocking. During control low sampling time can be used, since many objects are small and their time constants are usually 3 to 5 times longer than the time for closed system overclocking

$$T_{\text{ц}} \approx \frac{\sum T_i}{15 \div 50},$$

where, T_d – are constants of the control object.

In the study [21] devoted to microcontrollers in the section of the implementation of digital control, the theory and practice of choosing the discretization interval is summarized. The following recommendations are formulated:

- if the control object has a dominant time constant T_p, then the discretization interval T for a closed loop system can be chosen from condition $T < T_p / 10$;
- if for a closed loop control system the setting time of transient behavior T_{ss} or the natural frequency ω_n, then the discretization interval T is selected from the condition $T < T_{ss} / 10$ and $\omega_s > 10\omega_n$, $\omega_s = 2\pi / T$, where ω_n – is the sampling frequency.

In the scientific work of V.G. Zyryanov [13] noted that the discretization interval (step) T_0 is a very important parameter of the digital control system, since many of the coefficients of the discrete model of the "unchangeable part" of the open unadjusted automatic control system (ACS) depend on it, and therefore the quality indicators. Therefore, the synthesis of the digital control algorithm in general, with an unknown value, is possible only in the simplest cases that have no practical significance.

Traditionally, in accordance with the recommendations, a specific value T_0 is set, and then the analytical or the frequency method of the dynamic synthesis of digital ACS determines the transfer function of the digital corrector $W_{\text{цку}}(z)$. If necessary, the calculation is repeated many times for other, changed values T_0 (in case if the form is too complicated $W_{\text{цку}}(z)$, the quality indicators are not met, etc.) until a compromise result acceptable for practical implementation is obtained.

There are various recommendations for choosing a value T_0 in the synthesis of digital ACS. For example, in [22], sampling frequency is recommended to be approximately six times larger than the cutoff frequency of the continuous part of digital ACS.

The discretization of determinated signals with limited energy in accordance with the Kotel'nikov-Shannon theorem obtained a firm theoretical basis in the 1960s. However, the discretization of random signals has not yet found a satisfactory mathematical justification for applied problems, which in practice leads to an incorrect application of the sampling theorem and its incorrect interpretation in the digital signal processing [23].

According to Olson's formulation [24], the definition of an adequate sampling frequency for a control process is a non-trivial task, can rather be considered as art than a science, and represents a compromise between the requirements of the dynamics of the process and the performance of the computer and other technological mechanisms.

The analysis of scientific works indicates the presence of modern problems of real digital control systems synthesis. This is especially evident in the automation of control objects in the application area.

The purpose of the study is to develop a methodology for synthesizing a digital controller for a nonlinear control system for a linear dynamic object.

Object of research: the process of a digital control system for a nonlinear dynamic object with feedback.

The object of management is a road-building machine that has a hydraulic drive used as actuators of the automatic control system.

Research task. In order to ensure the quality of the transient process, which is close to the aperiodic nature of the change in the transient response, it is required to develop a method for parametric synthesis of a digital controller of a nonlinear linear object control system. The task of digital regulator synthesizing is solving in the applied area of control systems of RBM. During controller synthesizing, it is necessary to take into account the considerable inertia of the RBM hydraulic drive.

A nonlinear digital control system with feedback including a one-dimensional linear controlled object and a discrete regulator is considered.

A block diagram of a control system with a nonlinear gear (a "constraint" type link) is shown in Fig. 1.

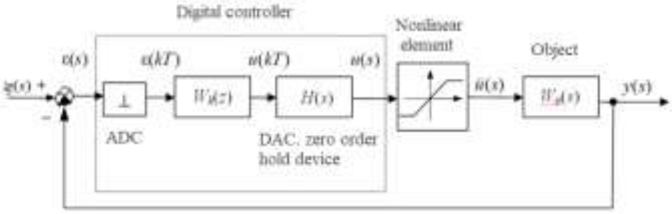

Fig. 1. Structural diagram of digital nonlinear control system

In Fig. 1 following notations were used: $W_o(s)$ – transfer function of control process; $W_y(s)$ – transfer function of controller; $g(s)$ – setting action; $\varepsilon(s)$ – control error; $u(s)$ – controlling action; $\bar{u}(s)$ – controlling action taking into account the influence of a non-linear element; $y(s)$ – output.

The control object has a transfer function $W_o(s)$ of the second order

$$W_o(s) = \frac{b_0}{a_0 \cdot s^2 + a_1 \cdot s + a_2}.$$

The transfer function of the open loop linear system with a PID controller has the form of:

$$W(s) = W_y(s) \cdot W_o(s) = \frac{K_d \cdot b_0 \cdot s^2 + K_p \cdot b_0 \cdot s + K_i \cdot b_0}{a_0 \cdot s^3 + a_1 \cdot s^2 + a_2 \cdot s}.$$

The saturation value and the type of nonlinear characteristic are determined by the design features of the hydraulic pump is used - adjustable, unregulated. Control is performed by changing the value of the control signal by the pump pressure.

With zero initial conditions, the range of the signal value changing of the set unit to the system is determined by limiting of the output variable of the nonlinear element to a single negative or positive value.

Then, the set value of output of the control variable (in the case under consideration, the speed of rotation of the hydraulic motor) is also limited by the transmission factor value of the control object transfer function. This does not contradict practice. Therefore:

$$\left|g(t)\right| \le W_o(0). \tag{2}$$

Under non-zero initial conditions, the range of the change in the signal value of the output variable of the system is also limited by the expression similar to (2)

$$\left|\Delta y(t)\right| \le W_o(0), \tag{3}$$

this imposes the restriction of non-zero initial conditions $y(0)$ to a possible assignment and leads to a change in the inequality (2). So, under positive values of $g(t) > 0$ and positive values of $y(0) > 0$, expression (2) in accordance with (3) will have the form

$$g(t) \le W_o(0) + y(0). \tag{4}$$

This expression will also be preserved for negative values $y(0) < 0$. It follows that under negative values of the zero condition and $g(t) > 0$ the following inequality holds: $\left|y(0)\right| < W_o(0)$.

Similar expressions can be obtained under negative values $g(t) < 0$. So, if the values are $y(0) < 0$, then (2) taking into account (3) will be

$$g(t) \ge -W_o(0) + y(0). \tag{5}$$

This expression is preserved even under positive values $y(0) > 0$. It follows that for positive values of the zero condition and $g(t) < 0$ the inequality also holds $\left|y(0)\right| < W_o(0)$.

III. Synthetic Methodology of the Digital Controller of Nonlinear Control System

When the digital controller is synthesized, the task of re-equipment is solved, which consists in replacing the continuous controller by a digital one, while preserving the most important properties of the continuous system, Fig. 1.

Taking into account the presence of nonlinearities of HG, considerable inertia of the HG systems used in RBM, the following algorithm of the synthesis methodology of digital automatic control systems is proposed, based on the concept of re-equipment of a continuous controller.

STEP 1. The regulator is synthesized as continuous according to known methods, including those published by the authors of the article as part of the international conference MMTT-27 (2014) and the All-Russian meeting in regards of management problems-2014 [1, 2].

STEP 2. The transition to the digital version of the controller is carried out according to the known expression [24] of the sampled data transfer function

$$M(z) = W_p(z)E(z) = \left[K_p + \frac{K_i\,Tz}{z-1} + \frac{K_d(z-1)}{Tz}\right]E(z). \tag{6}$$

The sampled data transfer function (6) of the digital PID controller corresponds to the difference equation:

$U(kT) = U((k-1)T) + a\,\varepsilon(kT) + b\,\varepsilon((k-1)T) + c\,\varepsilon((k-2)T)$, where, U – output variable of the digital PID controller; ε – input variable of the digital PID controller (control error); coefficients

$$a = (K_p + K_i T + K_d T^{-1});\ b = -(K_p + 2K_d T^{-1});\ c = K_d T^{-1}.$$

The sampling frequency is taken more than the passband of the continuous control system of the HG. How much is determined from further computer modeling and expert evaluation of the results obtained. As noted in the work of Olsson G. [24], the choice of frequency is more like art, reinforced by engineering intuition and practical experience.

STEP 3. Computer simulation is carried out for digital control options with selected sampling frequencies and recalculated parameter values according to formula (1). The scheme of the model is determined using the libraries of the Simulink environment and the modeling experience [25].

IV. Conclusion

There was proposed the synthesis methodology of a digital control system with an electrohydraulic drive peculiar to construction and road, agricultural and other mobile machines. The required quality of the control process is ensured by the rational determination of the sampling frequency of the closed loop digital controller. The methodology is based on the following postulate: the discretization interval is taken more than the passband of the continuous hydraulic drive control system. How much more is determined from further modeling and evaluation of the results obtained. The advantage of the method is the possibility of organizing interactive procedures for designing digital controllers of automatic control systems. Stages of constructing controller parameters can be most effectively implemented in the MATLAB&Simulink software environment.

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