Ensuring Accuracy in Steady State for Stabilization Non-stationary Object with Delayed Control*

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***Abstract*— Considered the method of solving the problem of ensuring accuracy in the steady state under traditional control of a technological object with variable parameters and with delayed control, consisting in the use of a two-circuit system of combined control, in which the action of the parametric perturbation is compensated, and which makes it possible to solve the problem with a sufficiently slow change in the parameters and in the presence of uncertainty in setting the lag value and the coefficients of the object model.**

Keywords*— *robust control systems; PID regulation law; delay

In this paper, object with a delay in control and with an uncertainty in the specification of the lag value and the variable parameters of the inertial part is considered. Assumed that the quasi-stationary hypothesis fulfilled, when during the time of control, the coefficients of the inertial part model are practically unchanged. However, since the regulation time is long, they can vary substantially. This corresponds to the assumptions of the method of frozen coefficients and is valid in many practical problems of control of technological processes.

Under these assumptions, the solution of the control problem in dynamics can be solved for constant median values of the inertial part of the parameters. It should be noted that the value of robust settings of the PID controller, because the regulator should provide qualitative control in the widest possible range of the object model variation coefficients. This increases the reliability of the system in the period between two adjacent retuning of the regulator. An alternative solution is to use more composite adaptive controls.

The main difficulty of constructing an adaptive control system is the presence of an indefinite management delay. At the present time, a number of works on adaptive control are known, where there is a lag in the output value or the state. Here, firstly, it should be noted systems in which the main contour is synthesized by the method of a sequential compensator [1–6]. Also here it is possible to note methods based on the procedure of backstepping [7–10].

In the presence of a control delay, a perturbation predictor is traditionally used to parry a parametric disturbance. It is rather simple to construct it if the perturbation mode and the magnitude of the delay are known. But in our case, neither is not known.

This raises the need to look for other solutions. One of these solutions is proposed in this paper on the basis of a robust approach for adjusting the parameters of the PID regulatory law and using the special structural scheme shown in Fig. 1.

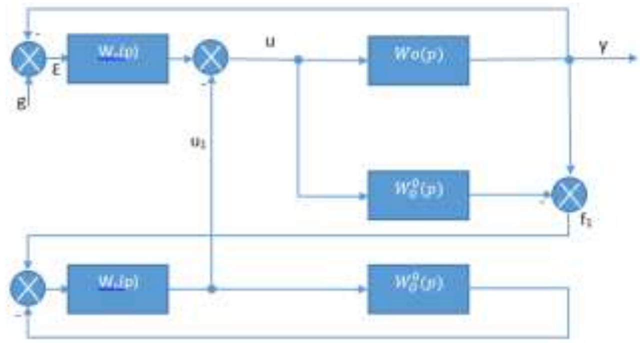

Fig. 1. Dual-circuit system

For an object with a delay in control, the adaptation time depends on the delay value. Therefore, the quality of stabilization is determined by the rate of change of parameters. As simulation practice shows, the accuracy of maintaining the output value in the 5% zone is achieved only for a sufficiently slow change in parameters so that the results of control under adaptive control can be commensurable with the results of robust control.

However, with variable parameters with such control, there arises the problem of ensuring the accuracy of a robust system in steady state, since there is a limited parametric perturbation in the system, which leads to a change in the output value in a certain range, depending on parameters amplitudes and the frequency range, in which these changes occur, as well as on the input impact.

If the control object is in the normal mode range, then the parametric disturbance can be considered limited, but changing in an infinite time interval. If the perturbation acts on a finite interval of time, then there are problems of control in dynamics. If the perturbation acts on an infinite interval, then it is necessary to solve the problems both in dynamics and in steady-state conditions.

In the dynamic range, the problem is solved by selecting robust settings of the PID regulation law. To increase accuracy in the steady state, a two-loop system can be used as the

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solution, which was previously proposed for parrying external bounded disturbances [11], [12]. Such structure is shown in figure 1.

Because of the presence of parametric uncertainty in the transfer function of the object $W_0(p)$ arises the disturbance f_1, for compensation of which an additional signal u_1 is used at the entrance of the object. When generating this signal, instead of the predictor, an additional nominal servo system. If, to assume that the output of the tracking system exactly coincides with f_1, then it can be used as a model, allowing to trace, additional movement at any point in the structural scheme, caused by the uncertainty of the mathematical model with respect to the nominal motion, to use these movements for control.

The variable u_1 obtained this way is used in the system to compensate for the effect of uncertainty on the output value. This approach allows to solve the problem of ensuring accuracy with uncertainty in setting of lag at the entrance of the object.

The introduction of a second circuit consisting of a servo system makes it possible to reduce the amplitude of the oscillations at the output, caused by change the object model parameters, in comparison with the single-loop system. It has been shown [1], [2], that such a system also has rudeness with respect to parametric uncertainty and lag, which corresponds to the robust of a single-loop system.

Therefore, it is important to create methods for robust control of a single-loop system in the class of traditional control laws, since they are mainly used in the automation of technological processes [13].

Based on the structural scheme, we obtain

$$f_1(p) = \Delta W(p) u(p), \qquad (1)$$

where $\Delta W(p) = W_0(p) - W_0^0(p)$.

$$u_1(p) = W_P(p) f_1(p) - W_P(p) W_0^0(p) u_1(p),$$

$$\varepsilon(p) = g(p) - y(p) = g(p) - \left(W_0(p) W_P(p) \varepsilon(p) - W_0(p) u_1(p)\right).$$

Get an error for the real movement

$$\varepsilon_1(p) = \Phi_{\varepsilon 1}(p) g(p), \qquad (2)$$

where $\Phi_{\varepsilon 1}(p) = \dfrac{1 + W_P(p) W_0(p)}{1 + 2W_P(p) W_0(p) + W_P^2(p) W_0^0(p) W_0(p)}$.

Also, for a single-loop real system

$$\varepsilon_2(p) = \Phi_{\varepsilon 2}(p) g(p), \qquad (3)$$

where $\Phi_{\varepsilon 2}(p) = \dfrac{1}{1 + W_P(p) W_0(p)}$.

As can be seen from the formulas (2), (3) for constant parameters of the object model uncertainty $\Delta W(p)$ and in the presence of an integrator in the transfer function $W_P(p)$ in both systems, astaticism is provided, since $W_P(p) \to \infty$ at $p \to 0$.

For a nominal single-circuit system

$$\varepsilon^0(p) = \Phi_\varepsilon^0(p) g(p), \qquad (4)$$

where $\Phi_\varepsilon^0(p) = \dfrac{1}{1 + W_P(p) W_0^0(p)}$.

With variable uncertainty parameters, consider the change of the error value in the two-loop (2) and in the single-loop system (3) in comparison with the nominal single-loop system (4). With $W(p) = W_0^0(p) + \Delta W(p)$

$$\Delta\varepsilon_1(j\omega) = \varepsilon_1(j\omega) - \varepsilon^0(j\omega) = I_1(j\omega) \Phi_\varepsilon^0(j\omega) g(j\omega), \qquad (5)$$

where

$$I_1(j\omega) = \frac{W_P(j\omega)\Delta W(j\omega)}{1 + W_P(j\omega)\left(W_0^0(j\omega) + \Delta W(j\omega)\right) + W_P(j\omega)\left(1 + W_P(j\omega) W_0^0(j\omega)\right)\left(W_0^0(j\omega) + \Delta W(j\omega)\right)}$$

$$\Delta\varepsilon_2(j\omega) = \varepsilon_2(j\omega) - \varepsilon^0(j\omega) = I_2(j\omega) \Phi_\varepsilon^0(j\omega) g(j\omega) \qquad (6)$$

where $I_2(j\omega) = \dfrac{W_P(j\omega)\Delta W(j\omega)}{1 + W_P(j\omega)\left(W_0^0(j\omega) + \Delta W(j\omega)\right)}$

The presence of an integrator in the transfer function $W_P(p)$ provides a greater reduction in the error modulus (5) in the low-frequency region compared to (6), because of the second contour, since in the denominator $I_1(j\omega)$ the transfer function $W_P(p)$ is present in the square, and in the numerator only in the first degree, and in the formula for $I_2(j\omega)$ everywhere only in the first degree.

If, for example, to estimate the accuracy, use the maximum values of the module for the quantities (5), (6), then for the same reference and for a given change in the uncertainty parameters ΔW in the low-frequency region in the two-loop system there is an additional mechanism for ensuring greater proximity of the accuracy index of the parametrically perturbed system to the accuracy of the nominal system.

For instance, consider the nominal transfer function of an object

$$W_0^0(p) = k_0^0 \frac{\exp(-10p)}{15p + 1}, \qquad (7)$$

where $k_0^0 = 1$.

As a transfer function of the regulator of a robust system, consider the PI law

$$W_P(p) = 0.0343 \frac{17p + 1}{p}. \qquad (8)$$

Suppose that in a real object the transmission coefficient varies in time according to the law

$$k_0(t) = 1 + 0.3\sin 0.01t\,. \qquad (9)$$

Then the transition characteristic of a single-circuit system (7), (8) has the form shown in Fig. 2. It is seen that in the steady state the curve goes beyond the 5% band. The corresponding curve for the two-loop system is shown in Fig. 3. It can be seen that all accuracy requirements are met here.

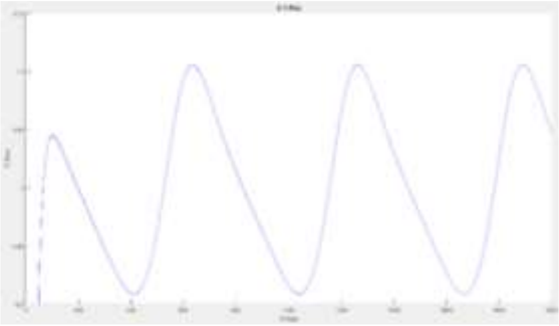

Fig. 2. The transition characteristic of a single-circuit system

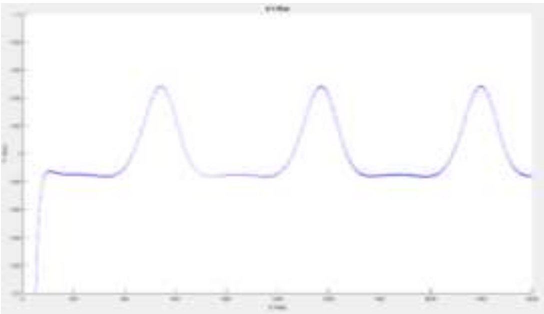

Fig. 3. The transition characteristic for the two-loop system

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