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APPLICATION PARALLEL FEEDFORWARD CORRECTION OF DYNAMIC OBJECTS IN THE ROBUST REGULATION TASKS

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Key words: staff controller, robust parallel feedforward object correction, robust regulation.
Abstract. The robust regulation mode, the main point of which composes the robusting parallel feedforward object correction, permitting to receive the stable regulation processes with staff controllers use is suggested.

ПРИМЕНЕНИЕ СОГЛАСНО-ПАРАЛЛЕЛЬНОЙ КОРРЕКЦИИ ДИНАМИЧЕСКИХ ОБЪЕКТОВ В ЗАДАЧАХ РОБАСТНОГО РЕГУЛИРОВАНИЯ

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Ключевые слова: штатный регулятор, робастная согласно-параллельная коррекция объекта, робастное регулирование.
Аннотация. Предлагается способ робастного регулирования, суть которого составляет робастизирующая согласно-параллельная коррекция объекта, позволяющая получать устойчивые процессы регулирования с применением штатных регуляторов.

Introduction

The synthesis of robust automatic control systems for a priori uncertain dynamic plants occupies an important place in modern control theory. There are various approaches to its solution [1, 2]: methods based on the Mikhailov and Nyquist frequency stability criteria. Tsypkin-Polyak locus, LMI and μ-synthesis methods, Lyapunov functions methods, Lipatov-Sokolov and Kharitonov interval stability criteria, LQ- and L1-optimization methods and optimization in Hardy spaces (methods H2- and H∞-synthesis), and others. In sprite of a great number of publications and considerable achievements in robust control problem a lot of urgent tasks still stay not only determined, but even not always quite formulated.

In the papers of authors [3-5] the idea of parallel feedforward correction of object dynamics in linear and nonlinear one-channel regulation systems in order to support the system of required robust properties.

In General, it should be noted that the parallel feedforward type of correlation was poorly studied in the frames of the classical theory of automatic control and is practically not affected in modern studies. The paper [6] shows that parallel feedforward correction is a very effective means of the desired change of the transmission and frequency characteristics of the control channel, unattainable in the frames of classical correction methods and very useful for solving a number of control problems.

Robust Controller Synthesis Task

Let us consider the single-circuit linear time-invariant regulation system with controller in direct circuit and unit negative feedback (fig. 1).

Let us denote by scalar variables u, y_0, g and ε - the regulating object input, its regulative output, desired output (command) and the regulation error accordingly.

Let us suppose, that regulation object is stable and aperiodic (without oscillation modes). Let us note, that wide class of industrial regulation objects answers the given requirements, and despite the fact that the stability's property, as a rule, one may support by preliminary object stabilization by means of negative feedback, relocating to weak enough damping of transients.

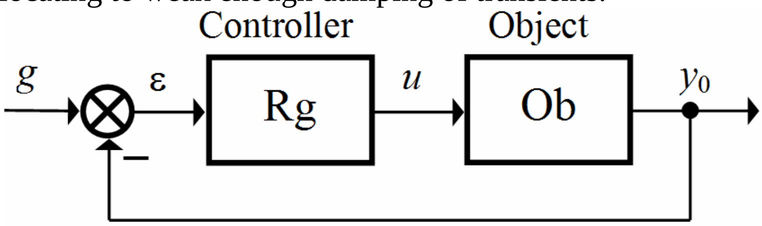

Fig. 1.

Synthesis controller task, supporting the robustness to regulation processes is posed. The term «robustness» interprets its initial meaning, introducing by G.E.P.Box as long ago as in 1953 and characterizing the conservation of stability system properties for variations of its parameters.

Robust Regulation Circuit

For regulation systems by stability aperiodic objects the following theorem is correct [3]:

***Theorem* 1**. Let weight function (unit impulse response) $K(t)$ $(t \geq 0)$ of regulation system open circuit answers the following conditions:

1) it's nonnegative: $\dot{K}(t) \leq 0 \;\; \forall\, t > 0$;

2) it's piecewise-smooth and integrable with its derivative;

3) it's monotone with its derivative $\dot{K}(t+\tau) \geq \dot{K}(t) > 0 \;\; \forall\, t, \tau > 0$.

Then amplitude-phase frequency response of open circuit system $W(j\omega)$ is placed in right half-plane, that is $\operatorname{Re} W(j\omega) \geq 0$, $-\infty \leq \omega \leq +\infty$. □

Proof. As far as

$$\operatorname{Re} W(j\omega) = \int_0^\infty e^{-j\omega t} K(t)\,dt = \int_0^\infty \cos(\omega t) K(t)\,dt,$$

then in the strength of 1) $\operatorname{Re} W(j\omega) \geq 0$ for $\omega = 0$,
and integration by parts with regard for 2) and 3) gives

$$\operatorname{Re} W(j\omega) = -\frac{1}{\omega} \int_0^\infty \sin(\omega t) \dot{K}(t)\,dt > 0 \text{ for all } \omega \neq 0.$$

Now using to considered system the classical frequency Nyquist stability criterion, it's not difficult to convinced of the correctness of the following theorem [3]:

***Theorem* 2**. Under the realization of theorem 1 conditions, the closed regulation system is stability and robust with respect to any disturbances of weight function $K(t)$, not disturbing the theorem 1 conditions.

Robust Ovject's Correction

Let us assume, that regulation object is stability, but its weight function doesn't answer the robust requiremens, serving the theorem 1 conditions.

Let us make the correction of object dynamics to support the realization of theorem 1 conditi-ons. To this end let us attach the correcting device (*Corrector*) parallel feedforward to object (fig. 2).

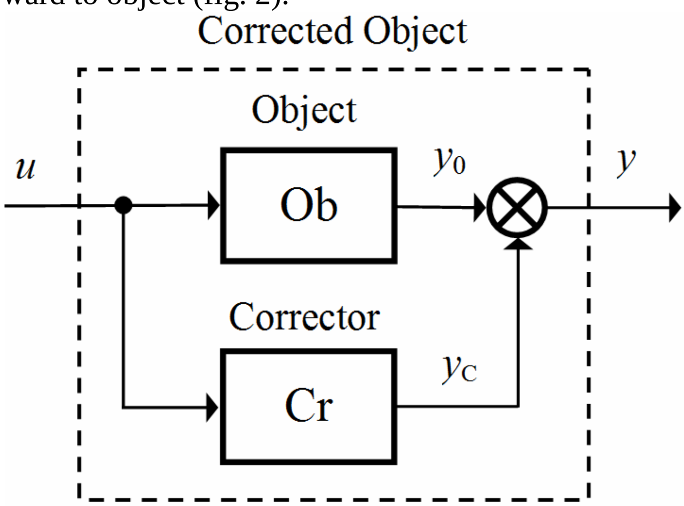

Fig. 2.

As a result of the given correction is the compound system «object + corrector» (*Corrected Object*), the output of which y is formed by summing up of outputs properly object y_0 and corrector y_C:

$$y = y_0 + y_C,$$

and weight function $K(t)$ may be represented in the form of

$$K(t) = K_0(t) + K_C(t),$$

where $K_0(t)$ and $K_C(t)$ – are weight function of object and corrector accordingly.

Thus the robusting object's correction task is consisted in choice of such weight function $K_C(t)$ of corrector, where weight function of corrected object $K(t)$ answers the theorem 1 conditions.

Robusting Correctors Types

The purpose of corrector is the formation of system's robust circuit regulation.

The robusting correction we'll call as *astatic correction*, and the corresponding corrector – as *astatic corrector*, if this correction doesn't influence on established mode of regulation system, that is $W_C(0)=0$. The inverse correction in a sense and the corresponding corrector we'll call *static*.

Let us denote by $R(s)$, $W_0(s)$ and $W_C(s)$ the transfer functions of controller, object and corrector accordingly. For the transfer function of system on channel «command – output» it's correct the following expression:

$$W_{gy_0}(s)=\frac{W_0(s)R(s)}{1+(W_0(s)+W_C(s))R(s)},$$

from which follows, that the system gain $W_{gy_0}(0)$ isn't depends on correction.

The simplest *static* and *astatic correctors* have the transfer functions accordingly as

$$W_C(s)=\frac{K_C}{T_C s+1};\ \ W_C(s)=\frac{K_C s}{T_C s+1}.$$

Let us assume, that the weight function of object $K_0(t)$ is decreased monotonically at $t>T>0$. Then one may try to restricted to the correction of object's weight function on interval $0\le t\le T$. The given consideration suggests about using the correctors with final memory, equal to T. In particular, one may assume

$$W_C(s)=K_C\left[\frac{\exp(1)-\exp(-Ts)}{Ts+1}-\frac{1-\exp(-Ts)}{Ts}\right].$$

The corresponding weight function is finitary and has the following form:

$$K_C(t)=\begin{cases}\dfrac{K_C}{T}\left[\exp\left(1-\dfrac{t}{T}\right)-1\right] & \text{for } 0\le t\le T,\\ 0 & \text{for } t>T.\end{cases}$$

Robust Regulation

Thus the corrected object answers the theorem 1 conditions, so according to theorem 2 it's possible to realize the robust regulation by means of staff (standard) controller (for example P-, PI- or PID-controllers). The corresponding block diagram of controller is represented on fig. 3: the robusting corrector, as a result, is attached counter-parallel to staff controller.

The given regulation method permits to simplify the controller structure essentially.

Really, let us assume, that the proper robusted correction is produced. Let us choose, for example, proportional link $R(s)=K_R=\text{const}$, as staff controller.

According to theorem 2, the regulation circuit is crude with respect to parameter $K_R>0$, that is in limiting case $K_R=\infty$, we'll get the following expression for the transfer function of system:

$$W_{gy_0}(s)=\frac{W_0(s)}{W_0(s)+W_C(s)}.$$

So, far example, at object with transfer function

$$W_0(s) = \frac{0,14s + 0,94}{(s+1)(0,2s+1)},$$

the weight function $K_0(t)$ has maximum for $t = 0,25\ln 1,5$, that is it's not answer the criteria conditions of the theorem 1.

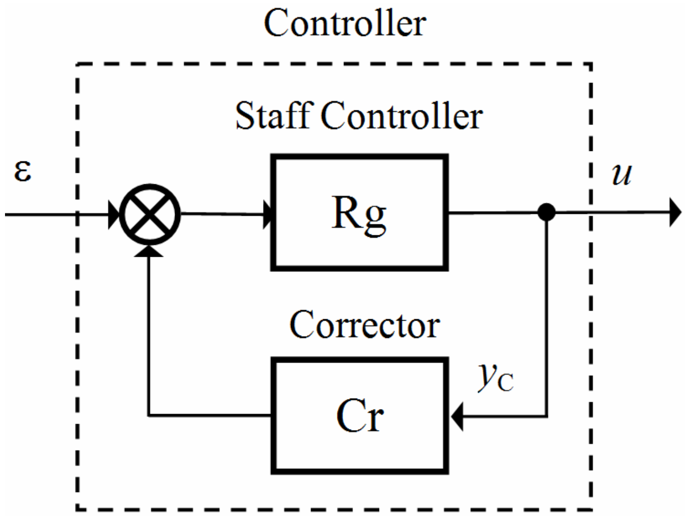

Fig. 3.

By means of correction

$$W_C(s) = \frac{0,02}{(0,2s+1)}$$

we'll get:

$$W(s) = W_0(s) + W_C(s) = \frac{0,16s + 0,96}{(0,2s+1)(s+1)}.$$

In closed system for $K_R = \infty$ we have

$$W_{\mathrm{gy}_0}(s) = \frac{0,14s + 0,94}{0,16s + 0,96} = 1 - \frac{0,02}{0,16s + 0,96}.$$

As a result the closed regulation system has the following performances index:

– small regulation time: $t_{\mathrm{reg}} \approx 3 \cdot 0,16 = 0,48$;

– negligible static error: $\varepsilon(\infty) = 1 - W_{gy_0} \approx 0,02\,(2\%)$;

– high level of noise immunity: $\left\| W_{\eta y_o}(s) \right\|_\infty \le 0,02\ (2\%)$.

Robusting correction permits to consider also parametric disturbances of regulation object.

Let the uncertainty of object's model be represented in parametric form

$$K_0 = K_0[\mu, t],$$

where $\mu \in \mathbf{M}$ - is vector of uncertain model parameters, $\mathbf{M}$ - is compact set.

Then it's necessary to design the corrector, which «makes more crude» the regulation channel according to the requirements to theorem 1 for all considered parametric disturbances of object.

So, in case of object with transfer function in the form of

$$K_0[\mu, t] = \frac{1}{(T_0(\mu)s + 1))^2},$$

where

$$T_0(\mu) = 1 + \mu, \ \mu \in [0,1],$$

the requirement correction is reached for

$$W_C(s) = \frac{0{,}2}{0{,}4s + 1}.$$

Robusting Correction in Absolute and L_2-Stability Tasks

The robusting correction use may be useful in absolute stability tasks [4]. Really, let in regulation channel be nonlinear link. Then the object's correction may be direct to receiving amplitude-phase frequency response $W(j\omega)$ $-\infty \le \omega \le +\infty$ of open regulation system, answering the requirements of circular stability criterion. As far as the circular stability criterion is extended and on linear no time-invariant systems in terms of L_2-stability, then the robusting correction is used to objects with no time-invariant link in regulation channel.

Conclusions

The suggested method of robust regulation is simple enough in the sense of technical realization. It's distinctive singularity is, that the accent in solution of robust regulation task is transfered from controller to regulation object, then as a result the robust regulation is realized by means of staff controller.

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