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Odessa National Academy of Food Technologies

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BLACK SEA SCIENCE 2021

Information Technology, Automation and Robotics

Proceedings

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STUDY OF METHODS OF SETTING THE AUTOMATIC CONTROL SYSTEM OF INDUSTRIAL CONTROL SYSTEMS

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Abstract

In this scientific paper the methods of tuning the automatic control system of industrial control systems are considered. Methods for determining the optimal tuning parameters of the controllers are considered: a formula method for determining the controller tuning; adjusting the controller by nomograms; experimental method for determining the setting; automatic adjustment system of the controller based on PTC APCS. This topic is relevant in the field of automation and control.

The settings of the regulators should be chosen so that the specified stability margin is provided in the closed-loop automatic control system (ACS), while the selected control quality indicator should be no worse than the required one. In the practice of commissioning, approximate formulas are widely used to determine the optimal tuning parameters for controllers.

Since in the theory of automatic control the stability margin can be assessed in different ways, and various indicators of the quality of regulation are used, several methods are used in engineering calculations to determine the optimal tuning parameters of the regulators. Formula method for determining the setting of the regulator, setting the regulator according to nomograms, experimental method for determining the setting of the controller [1].

The experimental method for determining the setting of the ACS allows, by the type of the transient process in the system, to determine such a direction of change in the parameters of the dynamic adjustment of the regulator, which will provide the desired change in the nature of the transient process. The advantage of which is the absence of the need to determine the absolute values of the controller settings.

Methods of tuning the automatic regulation system of industrial control facilities are considered below

Keywords: *Formula method, P-controller, PI-controller, PID-controller, transient, PTC, tuning, system, automatic control.*

Formula method to determine controller settings

In the practice of commissioning, approximate formulas are widely used to determine the optimal tuning parameters for regulators. The method is used for fast, approximate estimation of the values of the regulator settings for three types of optimal typical control processes. The method is applicable both for static controlled system with self-regulation (Table 2), and for controlled system without self-regulation. (Table 3).

Table 2 - Formula-based method for determining controller settings for static controlled system without self-regulation.

Regulator	Typical regulatory process		
	Aperiodic	With 20% overshoot	J_{min}
I	$K_p = \frac{1}{4.5K_{oy}\tau}$	$K_p = \frac{1}{1.7K_{oy}\tau}$	$K_p = \frac{1}{1.7K_{oy}\tau}$
P	$K_p = \frac{0.3}{K_{oy}\,\tau/T}$	$K_p = \frac{0.7}{K_{oy}\,\tau/T}$	$K_p = \frac{0.9}{K_{oy}\,\tau/T}$
PI	$K_p = \frac{0.6}{K_{oy}\,\tau/T}$ $T_{\grave{e}} = 0.6T$	$K_p = \frac{0.7}{K_{oy}\,\tau/T}$ $T_{\grave{e}} = 0.7T$	$K_p = \frac{1}{K_{oy}\,\tau/T}$ $T_{\grave{e}} = T$
PID	$K_p = \frac{0.95}{K_{oy}\,\tau/T}$ $T_{\grave{e}} = 2.4\tau$ $T_{\ddot{a}} = 0.4\tau$	$K_p = \frac{1.2}{K_{oy}\,\tau/T}$ $T_{\grave{e}} = 2\tau$ $T_{\ddot{a}} = 0.4\tau$	$K_p = \frac{1.4}{K_{oy}\,\tau/T}$ $T_{\grave{e}} = 1.3\tau$ $T_{\ddot{a}} = 0.5\tau$

DYNAMIC CHARACTERISTICS OF THE REGULATED OBJECT

(determination of controller settings by calculation method) Fig . 9

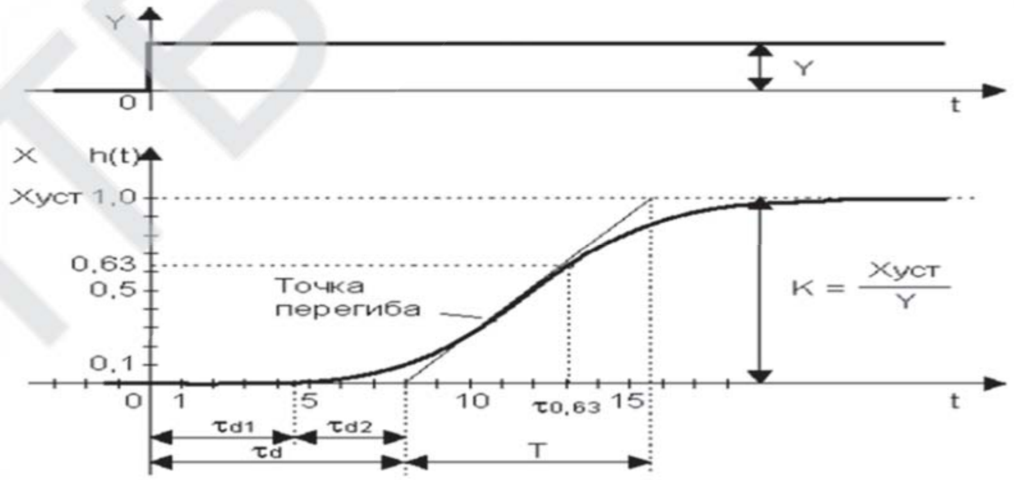

Fig . 9. Transient response of controlled system with self-regulation

The dynamic characteristic of the controlled system(acceleration characteristic, acceleration curve) is a graph of the change in the controlled value over time as a result of an abrupt disturbance applied to the system. Of greatest practical interest is the study of dynamic properties under disturbances from the regulatory action. Dynamic characteristics determine the nature of the change in time of each output parameter with a change in each input value.

Dynamic characteristics are expressed in the form of differential and integral equations where T, τ, Coe - time constant, delay and gain of the system. In these formulas it is assumed that a regulator with dependent settings is being tuned, the transfer function of which has the form:

$$W_p(p) = K_p\left(1 + \frac{1}{T_u p} + T_\partial p\right),$$

where K_p– controller gain

T_u – controller integration constant;

T_∂– differentiation constant.

Table 3 . Formula-based method for determining controller settings of the controlled system without self-regulation

regulator	Typical regulatory process		
	Aperiodic	With 20% overshoot	$\min\int_0^\infty \varepsilon^2 dt$
P	$K_p = \frac{0.4}{\tau/T}$	$K_p = \frac{0.7}{\tau/T}$	-
PI	$K_p = \frac{0.4}{\tau/T}$ $T_è = 6T$	$K_p = \frac{0.4}{\tau/T}$ $T_è = 3T$	$K_p = \frac{1}{\tau/T}$ $T_è = 4T$
PID	$K_p = \frac{0.6}{\tau/T}$ $T_è = 5\tau$ $T_ä = 0.2\tau$	$K_p = \frac{1.1}{\tau/T}$ $T_è = 2\tau$ $T_ä = 0.4\tau$	$K_p = \frac{1.4}{\tau/T}$ $T_è = 1.6\tau$ $T_ä = 0.5\tau$

Optimal adjustment of controllers according to nomograms

In contrast to the formula method, the calculation method using nomograms allows you to more accurately determine the controller settings, since takes into account the presence of a nonlinear relationship between the settings of the regulator and the value of the ratio τ / T.

There are nomograms for calculating the settings of PI and PID controllers for systems of the first and second orders with delay [1].

The nomogram for the PI controller settings is shown in Fig . 10.

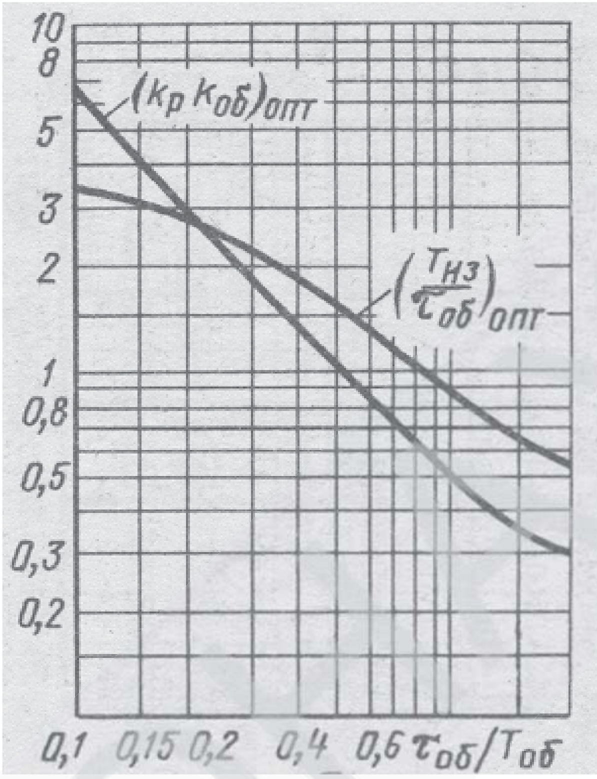

Fig . 10. Adjustment of the controller by nomograms.

Let us suppose that the controlled system is described by a first-order link with delay, and the optimal control process is a process with 20% overshoot. It should be borne in mind that modern electronic and microprocessor controllers implement PI and PID control laws with dependent settings, and pneumatic controllers - with independent settings of the form

$$W_p(p) = K_p\left(1 + \frac{1}{T_u p} + T_\partial p\right).$$

The differential component of industrial regulators is usually implemented in the form $\frac{K_{p\partial} T_f p}{T_f p + 1} \rightarrow T_\partial p$,

where $K_{p\partial}$ – regulator gain for the differential component (selectable in the range 1 - 10);

T_f – filter time constant.

These parameters are determined from the relation $K_{p\partial} T_f = T_\partial$.

The higher the interference level in the output signal of the object, the less it is recommended to take the value of Kpd. This will help to reduce the value of the mean square error of regulation [2].

Experimental methods of controller adjustment procedure

Undamped oscillation method

In the operating system, the integral and differential components of the controller are turned off (Ti = ∞, Td = 0), i.e. the system is translated into the P-law of regulation. By successively increasing K_p with a simultaneous supply of a small step-like signal, the targets are achieved in the system for sustained oscillations with a period of Kkp. This corresponds to bringing the system to the boundary of oscillatory stability.

When this mode of operation occurs, the values of the critical gain of the controller Kkp and the period of critical oscillations in the system Tkp are fixed. When critical fluctuations appear, not a single variable of the system should reach the limitation level. The Kkp and Tkp values are used to calculate the controller settings:

P-regulator: $K_p = 0.55\ K_{kp}$;

PI-regulator: $K_p = 0.45\ K_{kp}$; $T_u = T_{kp}/1.2$;

PID-regulator: $K_p = 0.6\ K_{kp}$; $T_u = T_{kp}/2$; $T_\partial = T_{kp}/8$.

The controller settings can be calculated using the critical frequency of the actual control system ωkp. Considering that the natural frequency ωkp of the controlled system coincides with the critical oscillation frequency of a closed-loop system with a P-controller, the values of Kkp and Tkp can be determined from the amplitude and period of critical oscillations of the controlled system itself.

When a closed system is brought to the boundary of oscillatory stability, the amplitude of oscillations can exceed the permissible value, which in turn will lead to an emergency at the facility or to the release of defective products. Therefore, not all industrial facility control systems can be brought into critical operation.

Damped oscillation method

The use of this method allows you to tune controllers without bringing the system to critical operating modes. Just as in the previous method, for a closed-loop system with a P-controller, by successively increasing K_p, a transient process of working out a rectangular pulse is achieved by a reference signal or a disturbance with a damping decrement D = 1/4.

Next, the period of these oscillations T_u .and the values of the integration and differentiation constants T and Td are determined

for PI-regulator: $T_u = T_\kappa/6$;

for PID regulator: $T_u = T_\kappa/6$; $T_\partial = T_\kappa/1.5$.

After setting the calculated values of T_u and T_∂ on the controller, it is necessary to experimentally clarify the value of K_p to obtain the damping decrement D = 1/4. For this purpose, an additional adjustment of K_p is performed for the selected regulation law, which usually leads to a decrease in K_p by 20 ÷ 30%. A similar tuning method is used in adaptive regulators of the American firm Foxboro.

Most industrial control systems are considered to be of good quality if their damping decrement D is equal to 1/4 or 1/5.

Currently, a new method of tuning closed-loop control systems has been developed, based on the supply of trial sinusoidal oscillations to the input of the regulator. By the amplitude and phase of the oscillations of the output signal of the control object, the PI-controller settings are calculated based on the condition of ensuring the specified oscillation index M and the maximum ratio K_p/ T_u.

Experimental methods of controller setting

For a significant number of industrial control systems, there are no sufficiently accurate mathematical models that describe their static and dynamic characteristics. At the same time, it is very expensive and laborious to carry out experiments to measure these characteristics.

The experimental method of adjusting the regulators does not require knowledge of the mathematical model of the system. However, it is assumed that the system is installed and can be put into operation, and it is also possible to change the settings of the regulator. Thus, some experiments can be carried out to analyze the effect of changing the settings on the dynamics of the system. Ultimately, it is guaranteed that good settings are obtained for a given control system.

Setting the regulator includes three sequential stages:

- at the first stage, the minimum value of K_p and an overestimated value of T_u (for example, $T_u \approx$ Tb) are set at the RU; this ensures the deliberately stable operation of the ACS, an aperiodic component is observed in the transient process;

- at the second stage, at constant T_u gradually increases K_p, achieving the appearance of an oscillatory component in the aperiodic transient process; at this stage, there is no need to strive for the realization of specific values of the degree of damping, but weak damping of oscillations in the transient process should be avoided;

- at the third stage, the aperiodic component of the paths of a gradual decrease in T_u is eliminated at a constant value of K_p, obtained at the second stage. A sign of the elimination of the aperiodic component in the transient process can be considered the approximate equality of the second and third vibration amplitudes. If, with decreasing T_u, in addition to the disappearance of the aperiodic component, a decrease in the damping of the oscillatory component occurs, then this will be a sign that the optimal value of T_u has already been passed. The T_u found at this stage is the optimal T_u opt. Fig . 11 Setting ACS by the type of transition.

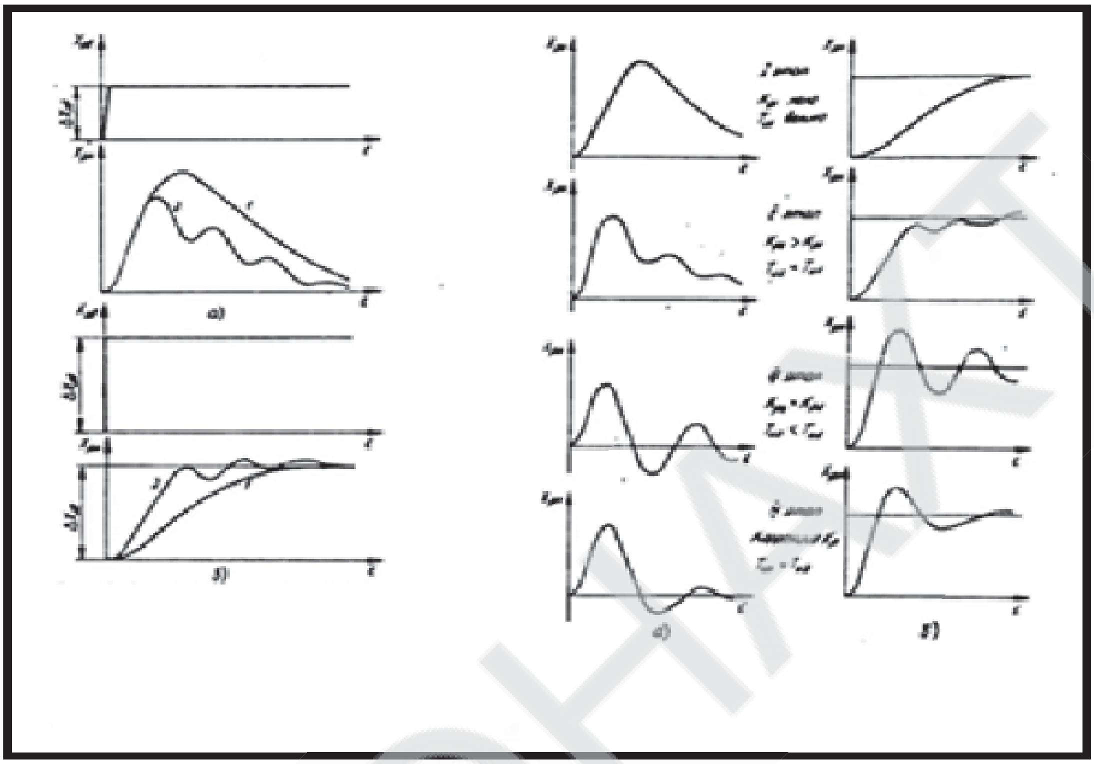

Fig . 11. Setting ACS by the type of transition.

Automatic setting system based on PTC APCS

In recent years, there has been a significant increase in interest in the issues of adjusting the regulators of industrial automatic control systems (ACS). This is associated with higher material and temporary costs, which arise both as a result of the operation of systems that do not work in optimal modes, and as a result of the inappropriateness of the maintenance of frequent re-heading. In this case, the setting is carried out, as a rule, manually and not in the best way, which also leads to substantial economic losses.

The main task of automatic control systems is to stabilize the process parameters at a given level when exposed to external disturbances acting on the control system.

A natural trend in the development of commercial PID controllers is the development of methods that reduce the cost of human labor for their installation, tuning and maintenance. Despite the fact that many of the methods of automatic tuning and adaptation of PID controllers used today were developed back in the 60s, in industrial controllers the adaptive technique began to be used only in the mid-80s. This is due to the technical complexity of implementing adaptive algorithms on an element base, which existed before the advent of microcontrollers.

The advent of digital programmed control made it possible to create and introduce into production controller automatic adjustments of the technological process control system. Many process systems require sophisticated controls to ensure optimal process flow. The practical use of pre-emptive concepts is one of the hallmarks of technological advances in management. The use of pre-emptive technology and the input of the model into the control algorithm creates an additional advantage - stability. This means that changes in the dynamic characteristics of the control system, which inevitably arise during long-term operation, practically do not affect the quality.

Fully automatic tuning can be initiated when a predetermined condition occurs, for example, when the load changes, when external influences change, when the control error changes, or continuously in time. Automatic tuning, initiated without human intervention, is called adaptation.

The technology of anticipatory action, the basis of which is the input of the model of the controlled system into the control algorithm.

PTC - APCS applies the concept of pre-emptive action. Its use eliminates overshooting of the automatic control system and significantly reduces the time of process regulation. The use of pre-emptive technology and the input of the model into the control algorithm create an additional advantage - stability. This means that changes in the dynamic characteristics of the control system, which inevitably arise during long-term operation, practically do not affect the quality of regulation.

In the future, the scientific work is explained by description and implementation with links to accompanying drawings, in which:

The PTC Automatic Tuning System can be initiated when a predetermined condition occurs, when the load changes.

An example of the automatic adjustment of the PTC of the APCS can be the fragment of the mnemonic diagram of the steam temperature controller behind the PRS GPP shown in the figure. (Fig . 12.)

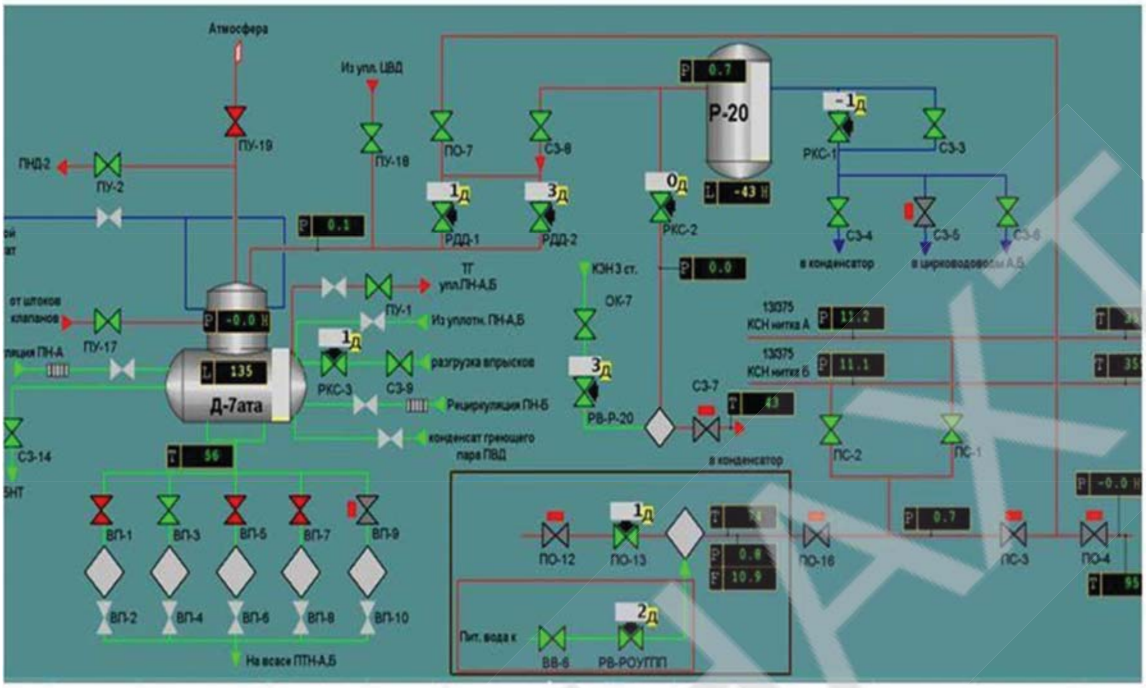

Fig . 12. fragment of the mnemonic diagram of the steam temperature controller behind the ROU GPP.

In Fig . 12 a fragment of the mnemonic diagram of the steam temperature controller behind the RCU HR (reduction cooling unit for hot reheat), steam coming from the secondary superheated steam collector, through the RCU HR (PO-13) are shown. It supplies steam to the auxiliary collector (KSN).

Temperature controller RV-RCU-HR maintains the steam temperature behind the RCU HR. The concept of anticipatory action, the principle of operation is to introduce the model of the controlled system into the control algorithm.

The red line and the square denote the technology of anticipatory action, the basis of which is the introduction of the model of the controlled system into the control algorithm. (Fig . 13)

All types of automatic adjustment use three fundamentally important stages: identification (determination of the dynamic characteristics of the regulation); calculation of controller parameters; setting. Often, the final stage includes a tuning stage (final tuning optimization). Optimization of the tuning is necessary due to the fact that the methods for calculating the parameters of the controller according to the formulas are simplified, do not take into account the nonlinearities of the system, in particular, the always present nonlinearity of the "constraint" type, identification of the parameters of the system is performed with some error. It is important to emphasize that despite the presence of "automatic" tuning, the controller may not provide the required quality of regulation for reasons that do not depend on the quality of the algorithms embedded in it.

For example, the control system may be poorly designed (dependent control loops, long delay, high system order); the system can be non-linear; the sensors may be located in the wrong place and have poor contact with the system, the level of interference in the measurement channel may be unacceptably high; the resolution of the sensor may not be high enough; the source of the input influence on the object may have too much inertia or hysteresis; there may also be errors in the installation of the system, poor grounding, broken conductors, etc.

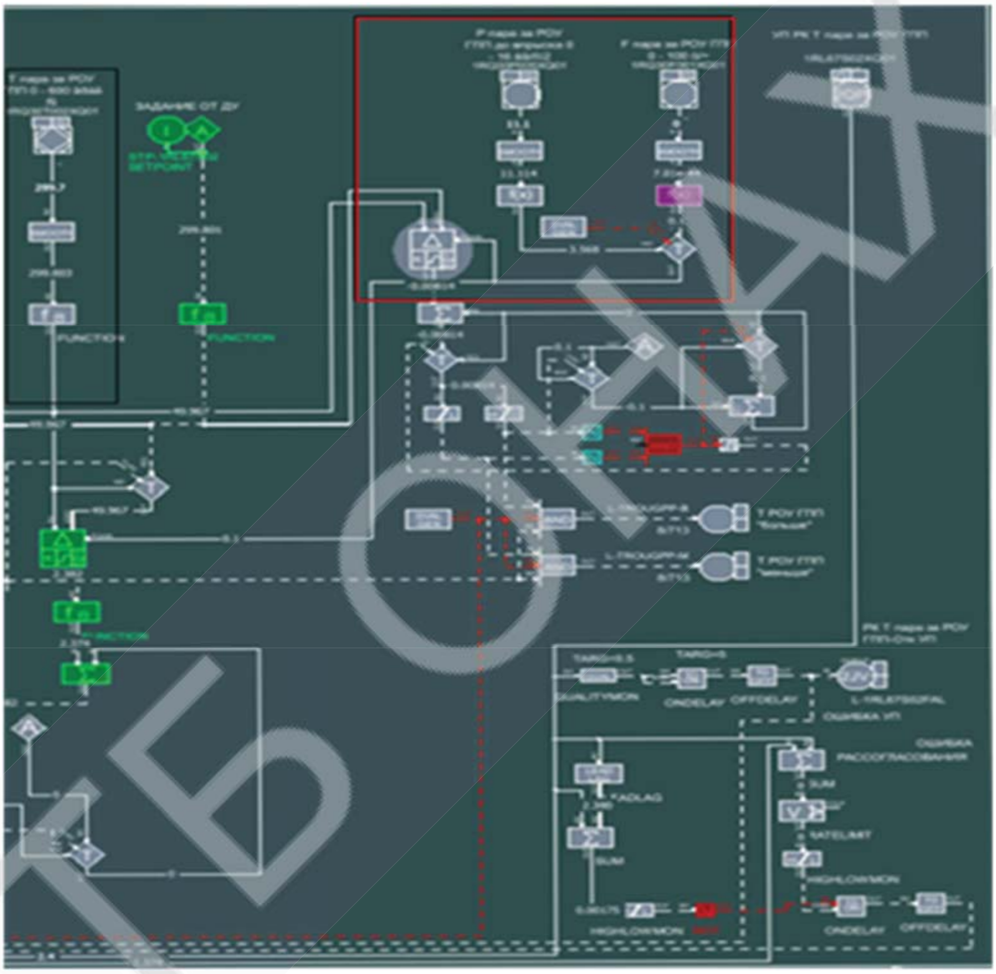

Fig . 13. Scheme of automatic adjustment of the steam temperature controller behind the RCU HR, with the technology of anticipatory action

Therefore, before starting the automatic adjustment, you must make sure that the listed problems are not present. For example, if, due to wear on a mechanical system, a hysteresis is not foreseen by the design appears and therefore the system is in oscillation mode, adjusting the controller may not give the desired result until the cause of the problem is eliminated.

The main stage of automatic adjustment and adaptation is the identification of the system model, it is performed in an automatic mode.

Fig . 14 shows the general structure of the system with automatic adjustment [3].

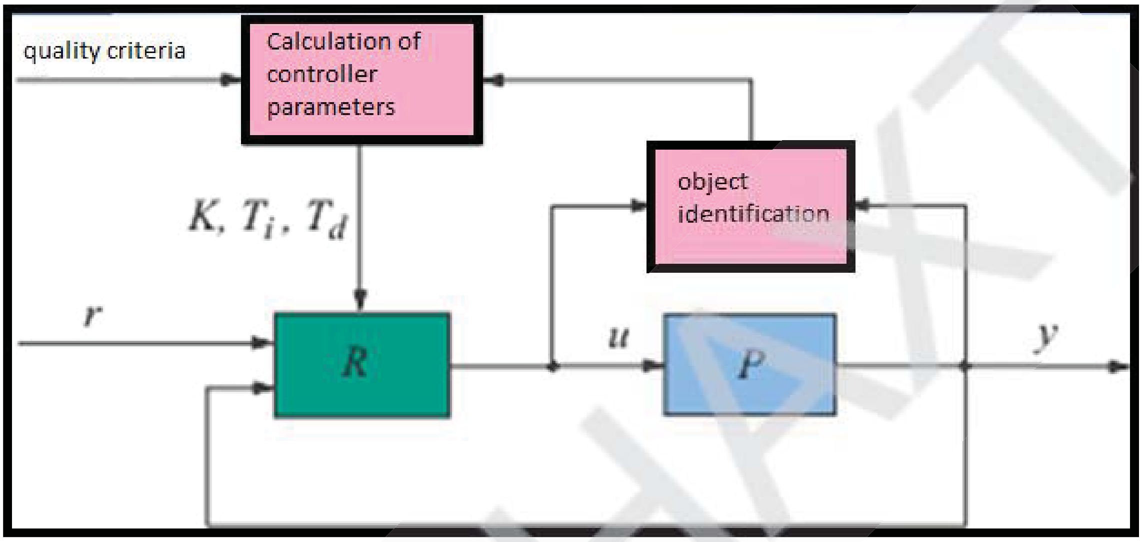

Fig . 14. General system structure with automatic adjustment.

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