JUSTIFICATION OF THE CONTROLLER PARAMETERS IN AUTOMATIC THERMAL CONTROL SYSTEM OF ELECTRIC THERMAL AGGREGATE

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Abstract On the basis of the structural diagram of the thermal aggregate temperature ACS with structural limitations and assumptions liberalized the control system. Parameters of the PID controller were optimized in accordance with the required quality parameters. Check of the adequacy of the Simulink-model showed good convergence between the results of mathematical modeling and full-scale experiment. Due to the presence of dead zones in the characteristic of the thyristor voltage regulator: delayed transient rise of temperature in the thermal aggregate, the growth process is oscillatory. Presented the transient graphs with the following results: good coincidence of natural experiment and mathematical modeling results (rms error is 5.7 °C); because of the dead zone in the characteristics of the thyristor voltage regulator: delayed transition process growth temperature in the thermal aggregate and the growth process is oscillatory; transients rise in the temperature of the furnace takes place without overshoot. Identified options PID controller, providing specified quality parameters. Developed the Simulink-model ACS furnace temperature with the structural restrictions. Check of the adequacy of Simulink - model showed a good convergence of results of mathematical modeling and natural experiment.

Keywords: electrical furnace, temperature control, analog regulator

Introduction. In [1-3] described laboratory function of the control object (the electrical facility and mathematical model of the automatic heating furnace and the temperature sensor) is the thermal aggregate based on the transfer control systems (ACS) temperature electric heating illustrated in fig. 1 [4].

For the justification of the controller parameters accept indicators of the quality of temperature control system.

ACS temperature furnaces must provide the following quality parameters when developing a task to a temperature equal to $T_z=80^\circ\text{C}$ (voltage at the terminals of the furnace $U_{np}=70\text{V}$): allowable overshoot $\delta_z=6\%$; permissible static error $\delta_s=0^\circ\text{C}$; regulation time $t_{pr}=2400\text{ s}$.

Structural diagram ACS temperature shown in fig. 1, it is nonlinear. For its research methods of linear systems, linearize control system. We use the following assumptions:

- controller $W_p(p)$ output unlimited;
- characteristic of the thyristor voltage regulator linear in all range changes input signal.

The corresponding structural diagram is shown in fig. 2.
The transfer function of the connection of the phase regulator and thyristor voltage regulator in view of the assumptions, V/mA

\[ W_{np}(p) = K_{np} = \frac{U_{in}}{I_{p_{\text{max}}} = \frac{70}{20} = 3.5 \]  

where \( I_{p_{\text{max}}} = 20 \text{ mA} \) - output current of the regulator, whereby the voltage at the terminals of the furnace \( U_{n} = U_{n_{\text{z}}} = 70 \text{ V} \).

The equivalent transfer function of the controlled system.

\[ W_{o}(p) = W_{np}(p) = W_{n}(p) = K_{n} \frac{K_{p}}{T_{np} + 1} = \frac{3.5 \times 2.46}{2400p + 1} \] (2)

To calculate the controller is used the Matlab program package [5].

The initial transfer control function can be written as

\[ W_{p}(p) = K_{p} \frac{T_{p}p + 1}{p} \] (3)

Taking \( K_{p}=1, T_{p}=1 \), obtain:

\[ W_{p}(p) = \frac{p + 1}{p} \] (4)

In the command line Matlab introduce equivalent transfer function of the controlled system \( W_{o} = tf([8,61], [2400 1]) \) and the initial transfer control function \( W_{p} = tf([1 1], [1 0]) \).

\[ >>W_{o} = tf([8,61], [2400 1]) \text{ Transfer function:} \]

\[ \frac{8,61}{2400s + 1} \]

\[ >>W_{p} = tf([1 1], [1 0]) \text{ Transfer function:} \]

\[ \frac{1}{s + 1/s} \]

Open the application SISO Design Tool [6, 7]. Import transfer functions \( W_{o} \) and \( W_{p} \) in a generalized system structural diagram. Correction controller until obtain the desired control time \( t_{p} = t_{p_{\text{z}}} = 2400 \text{ s} \) and with overshoot \( \delta \leq \delta_{\text{z}} = 6\% \). We can do it using either root locus (left box in fig. 3) or logarithmic frequency response and phase frequency response of a logarithmic open loop (right box in fig. 3).

Figure 2. Structural diagram of the linearized ACS temperature furnace

Figure 3. Setting control
As a result of setting the transfer function obtained by PI-regulators:

$$W_R(p) = \frac{0.00048931 \times \left(1 + \frac{1}{1300p}\right)}{1300p} = 0.636 \left(1 + \frac{1}{1300p}\right)$$

$$K_p = 0.636, \quad T_p = 1300.$$  

The transition process in the system corresponding to controller configuration parameters is shown in fig. 4.

The coefficients of PI-regulators are:

Check of the adequacy of the mathematical model. Structural diagram ACS temperature in the furnace with numerical values of controller parameters and including all of nonlinearities is depicted in fig. 5.

Materials and methods. To check the reliability of the results made the mathematical modeling of temperature ACS taking into account nonlinearities (fig. 5), and also made a full-scale experiment in a laboratory facility. Scheme Simulink-model corresponding ACS furnace temperature with structural limitations shown in fig. 6. The diagram consists two subsystems:

1. Temperature control subsystem with limitation (limited by the output value of 20 mA) [2, 8]:
   - subsystem phase regulator and a thyristor voltage regulator (implemented in accordance with the nonlinear characteristic given in [2,9, 10]).
   - Dead zone of the thyristor voltage regulator $TPH$:
In mathematical modeling and natural experiment are accepted the following values:

- the voltage across the terminals of the furnace $U_{nз} = 70$ V, a task to a during full-scale experiment $T_z = 80 \, ^{\circ}C$, a task to a temperature in the mathematical model $T_{zm} = T_z - T_{cp} = 80 - 14 = 66 \, ^{\circ}C$ ($T_{cp} = 14 \, ^{\circ}C$ - ambient temperature).

Set the following parameters of the PID regulator settings in the control unit regulators TZN4W [8]:

$$P = \frac{1}{K_p} = \frac{1}{0,636} = 1,572$$

$$I = T_z + 1300$$

**Figure 6.** Simulink-model ACS temperature in the furnace with all nonlinearities.

Fig. 7 shows a graph transition obtained in graphs are constructed based on deviations in the Simulink-model ACS temperature (curve 2), and a ambient temperature $T_{cp} = 14 \, ^{\circ}C$. graph of transient in a real system (curve 1).

The graphs are constructed based on deviations in the ambient temperature $T_{cp} = 14 \, ^{\circ}C$.

**Figure 7.** Comparison of the results ACS temperature mathematical modeling (2) and natural experiment (1).

Results. The transient graphs (fig. 7) show as following:

- good coincidence of natural experiment and mathematical modeling results (rms error is 5.7 OC).
- because of the dead zone in the characteristics of the thyristor voltage regulator.
– delayed transition process growth temperature in the thermal aggregate, - the growth process is oscillatory.
– transients rise in the temperature of the furnace takes place without overshoot.

Conclusions. Thus, as a result of the present work we can make the following conclusions 1. Linearized the structural diagram ACS temperature in the furnace with the structural restrictions for the calculation of the controller parameters;
2. Identified options PID-controller, providing specified quality parameters.
3. Developed Simulink - model ACS furnace temperature with the structural restrictions;
4. Check of the adequacy of Simulink - model showed a good convergence of results of mathematical modeling and natural experiment.

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