SYNTHESIS OF THE CONTROL ALGORITHM WITH THERMAL PROCESS IN THE OVEN

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INTRODUCTION

In the diverse technological processes can be necessary of control the thermal regime. The thermal processes represent the slow time - varying processes which can be characterized by the big inertia. In the most technical installations of thermal control are used the PID controllers, which are characterized by the good performance and robustness ensured in the automated system. By the its three components (proportional P, integrative I and derivative D), the typical controllers realize the basic functions as: adjusting the output value of the process in concordance with the tuning parameter of the P component, removing the errors in the stationary regime by the I component, predicting the future behavior of the process by the D component [6, 7].

The tuning of the controller in the control thermal systems is a difficult procedure. In the specialized literature are presented a lot of tuning methods the typical controllers: the empirical methods which are based on the classical methods of tuning the controller parameters developed by the Ziegler-Nichols and others, the graph-analytical methods and tuning methods which are based on the optimization techniques [2, 3, 8, 9].

The big number of these methods to be used require the known mathematical model of the industrial process. Knowing the mathematical model of the process requires using the identification procedures. Identification aims to obtain the mathematical model that would describe the static and dynamic characteristics of the industrial process.

In this paper is used the analytical and experimental methods of tuning the typical PID controller in the control thermal system, where control of the temperature is realized by the industrial controller TRM-151, OWEN firm [5, 7]. It was obtained the experimental curve of the oven and using the identification procedure was calculated the mathematical model of the oven. It is proposed to tune the PID controller by the maximum stability degree method with iteration and Ziegler-Nichols method. The obtained results are experimental verified by the installation and in the software package MATLAB.

1. DESCRIPTION OF THE DESIGNED SYSTEM

The principle scheme of the thermal control system is presented in the figure 1. The elements of the systems are: 1- the oven with heating element, 2 - the industrial controller TRM - 151, OWEN firm, 3 - the thermocouple temperature transducer TXK(L), 4 - interface AC3-M, 5 - PC. The oven is supplied with electrical energy from network of the alternative current 220 V. The oven was designed based on the following technical data: the oven volume V=500 cm^3, electrical power P=300 W, the maximal working temperature is T=400 °C.

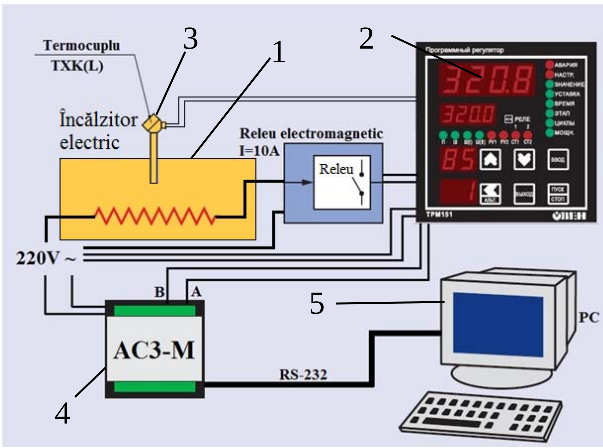

Figure 1. Principle scheme of the control system.

In the figure 2 is presented the structural block scheme of the control system, where $H_R(s)$ represents the transfer function of the controller, and $H_{PF}(s)$ - the transfer function of the control object (fixed part).

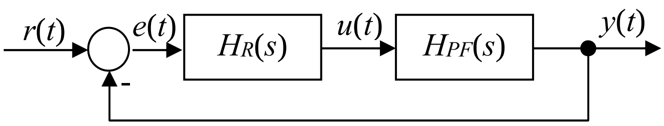

Figure 2. Block scheme of the control system.

2. IDENTIFICATION OF THE CONTROL OBJECT

To obtain the mathematical model of the oven was obtained the experimental curve of the temperature variation in the electrical oven, where the reference temperature was settled at the 207^0C. The experimental curve was registered by the TRM-151 and it is presented in the figure 3.

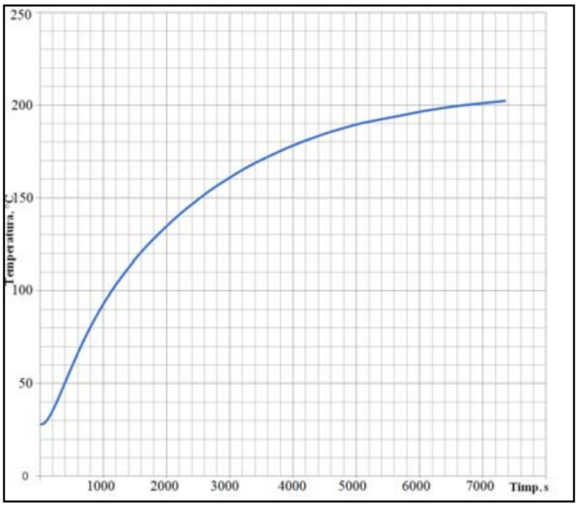

Figure 3. The experimental curve.

To estimate the model parameters of the control object was used the module Process Models from System Identification Toolbox from MATLAB and its interface is presented in the figure 4 and for identification was chosen the model object with inertia second order and time delay. In the figure 5 is presented the comparison between experimental curve - 1 with identified curve - 2.

Based on the identification procedure it was obtained the mathematical model described by the following transfer function:

$$H(s)=\frac{ke^{-\tau s}}{(T_1 s+1)(T_2 s+1)}=\frac{ke^{-\tau s}}{a_0 s^2+a_1 s+a_2}= \tag{1}$$
$$=\frac{207.06e^{-1.15s}}{(2125.9s+1)(34.034s+1)}=\frac{207.06e^{-1.15s}}{72352.88s^2+2159.93s+1}.$$

In the transfer function (1) are used the following notations: k transfer coefficient, T_1, T_2 - time constants, τ– time delay, $a_0=T_1T_2$, $a_1=T_1+T_2$, $a_2=1$.

In this paper is proposed to synthesize the standard control algorithm PID to the identified model object which is described by the following transfer function:

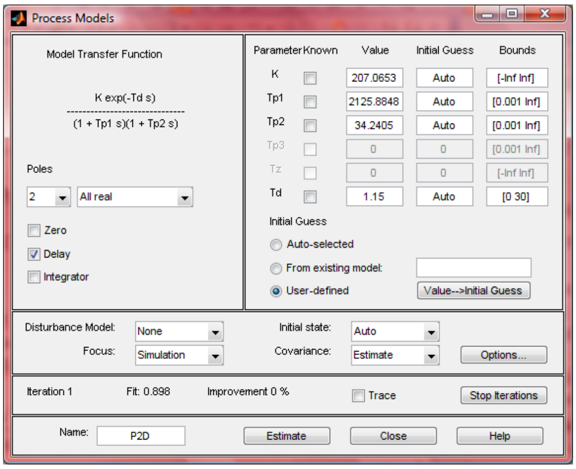

Figure 4. Identification interface by the package Process Models.

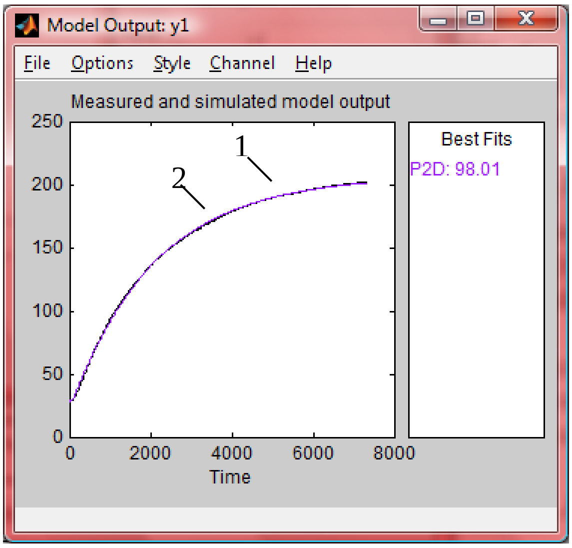

Figure 5. Comparison of the experimental curve with identified curve.

$$H_{PID}(s)=k_p+\frac{k_i}{s}+k_d s\,, \tag{2}$$

where k_p, k_i, k_d – represent the tuning parameters of the respectively controller.

3. METHODS OF TUNING THE PID CONTROLLER

3.1. The maximum stability degree method with iteration

The main problem in this method consists in ensuring for the respectively control laws the maximum stability degree of the designed control system. For the system structure which consists of fixed part with transfer function (1) and controller with transfer function (2) was obtained the characteristic equation of the closed loop system and based on the procedure of the maximum stability degree method was obtained the system from four algebraic equations [10-12]:

$$c_0 J^3 - c_1 J^2 + c_2 J - c_3 = 0, \tag{3}$$

where $c_0 = \tau^3 a_0; c_1 = a_1 \tau^3 + 9\tau^2 a_0,$

$$c_2 = a_2 \tau^3 + 6\tau^2 a_1 + 18\tau a_0,$$

$$c_3 = 3a_2\tau^2 + 6\tau a_1 + 6a_0;$$

$$k_p = (1/k)\exp(-\tau J)(a_0\tau^2 J^4 - J^3(\tau^2 a_1 + 5\tau a_0) + \\ +J^2(\tau^2 + 3\tau a_1 + 3a_0) - \tau J - 1) = f_p(J); \tag{4}$$

$$k_i = (1/(2k))\exp(-\tau J)J^3(a_0\tau^2 J^2 - J(\tau^2 a_1 + 4\tau a_0) + \\ +\tau^2 + 2\tau a_1 + 2a_0) = f_i(J); \tag{5}$$

$$k_d = (1/(2k))\exp(-\tau J)(a_0\tau^2 J^3 - J^2(\tau^2 a_1 + 6\tau a_0) + \\ +J(\tau^2 + 4\tau a_1 + 6a_0) - 2\tau - 2a_1) = f_d(J). \tag{6}$$

In the maximum stability degree method [1] the tuning procedure of parameters the PID controller consists in determination the optimal stability degree from equation (3), but the tuning parameters of the controller are calculated from (4)-(5) equations. From application, the maximum stability degree method in case of tuning the PID controller was observed that this method doesn't ensure the stability of the system, in case when tuning parameters were obtained for the value of the optimal stability degree by the expression (3).

To expend the possibilities of using the maximum stability degree method was proposed to use the maximum stability degree method with iteration and the tuning procedure is describing below [10-12].

From expressions (4)-(6) can be observed that the tuning parameters of the PID controller k_p, k_i and k_d depend of the model object known parameters and of the unknown stability degree J of the control system: $k_p=f_p(J)$, $k_i=f_i(J)$, $k_d=f_d(J)$. From the relations (4)-(6) at the known values of model object parameters and at the variation the stability degree $J \geq 0$ in the respectively limits is effectuated the calculation and constructed the dependencies $k_p=f_p(J)$, $k_i=f_i(J)$, $k_d=f_d(J)$ for determination the tuning parameters of the PID controller. Next are chosen the sets of the parameters values J-k_p, k_i, k_d for the optimal and quasi optimal values of J and for every set is done the computer simulation of the control system with PID controller with chosen sets of tuning parameters. In final is chosen the transient process that satisfied the imposed performance.

3.2. The Ziegler-Nichols method based on the step response

The Ziegler-Nichols method based on the step response permits to tune the typical P, PI and PID algorithms by the following way: based on the step response (figure 6) of the open loop system when as input is applied the step signal, it is determinate the model object parameters k_f, L, T_f, a. The parameters L and T_f are calculated based on the experimental curve in the following way:

$$L = t_1; \\ T_f = t_2 - t_1; \\ a = k_f \frac{L}{T_f}. \tag{8}$$

Based on these parameters are done the calculations of tuning parameters for P, PI and PID algorithms by the following relations:

- For the control system with P controller – $k_p=1/a$.
- For the control system with PI controller – $k_p=0.9/a$, $T_i=3L$.
- For the control system with PID controller – $k_p=1{,}2/a$, $T_i=2L$, $k_d=L/2$.

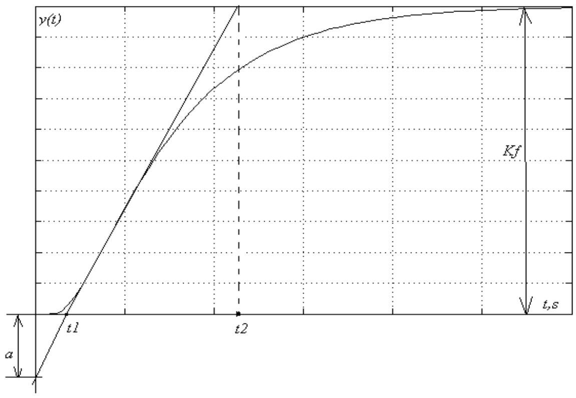

Figure 6. The response of he open loop system at the step signal.

4. COMPUTER SIMULATION

For analyzing the efficiency of tuning methods of the PID algorithm to the identified model object presented by the (1) transfer function, were done the respectively calculations of the tuning parameters based on the (4)-(6) expressions and were constructed the dependencies $k_p=f(J)$, $k_i=f(J)$, $k_d=f(J)$, which are presented in the figure 7. Based on the curves presented in the figure 7 were chosen the values sets J - k_p, k_i, k_d of the tuning parameters of the PID controller and these values are presented in the Table 1.

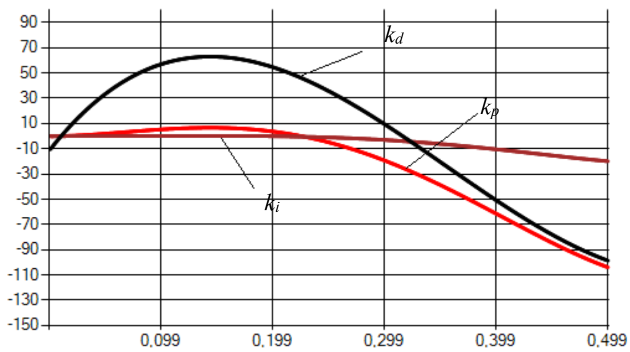

Figure 7. Dependencies $k_p = f_p(J)$, $k_i = f_i(J)$, $k_d = f_d(J)$ for the PID controller.

Next, it was done the calculation of the tuning parameters by the Ziegler-Nichols method based on the step response by the experimental curve (figure 8), using the expressions (8) were obtained the tuning parameters: $L = 189$; $T_f = 2211$; $k_f = 1.56$; $a = 0.13$ and the calculated parameters are presented in the Table 1.

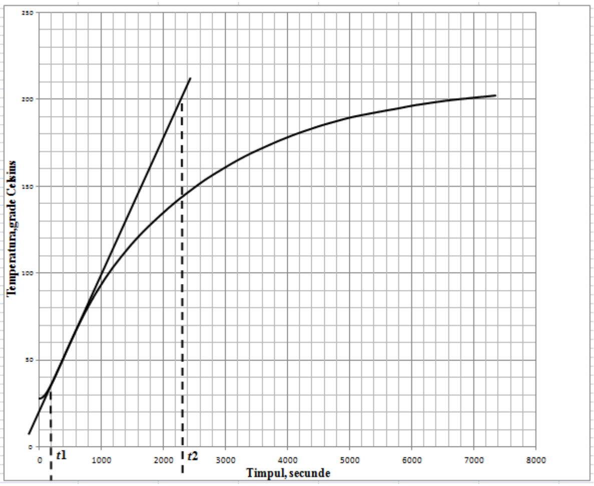

Figure 8. The calculation of the tuning parameters based on the experimental curve.

For verification the obtained results in case of tuning the PID controller to the model object (1) was done the computer simulation of the control system in the software package MATLAB and the simulation scheme is presented in the figure 9.

Transient processes of the control system are presented in the figure 10, where the numeration of the curves corresponds with iteration numeration from Tables 1, 2. In the Table 2 is presented the performance of the control system for the case of tuning the PID controller by the maximum stability degree method with iterations and Ziegler-Nichols method based on the step response.

Table 1. Tuning parameters of the PID controller.

Metoda acordare	**Nr. iter**	***J***	k_p	k_i	k_d
Metoda G.M.S.	1	0,02	0,39	0,002	10,038
	2	0,03	0,83	0,008	18,87
	3	0,19	4,12	0,004	55,76
Metoda Ziegler-Nichols			9.23	0.002	94.5

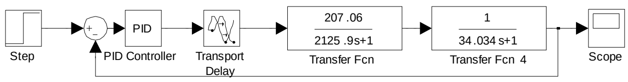

Figure 9. The simulation diagram of the control system.

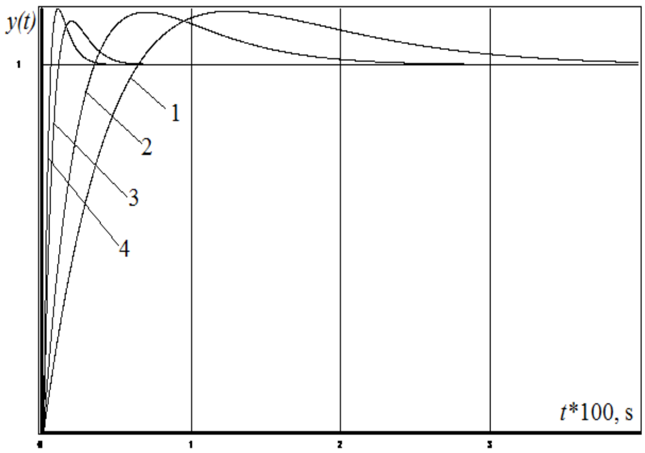

Figure 10. Transient processes of the control system.

From analyzing the transient processes from the figure 10, it can be observed that the best performance was obtained for the case of tuning the PID controller by the maximum stability degree method with iterations (curve 3).

Table 2. The performance of the control system.

Performance	**Nr. curve**	ε, %	t_c, s	σ, %	t_r, s	λ
Maxim. stabilit. degree method	1	5	57.5	14.5	249	1
	2	5	31.7	14.3	144.5	1
	3	5	10.1	11.8	33.6	1
Ziegler-Nichols	4	5	5.6	15	21.75	1

For analyzing the stability reserve of the control system with PID controller was obtained the poles distribution in the complex plane, that was calculated in MATLAB (figure 11), where the numeration of the poles corresponds with numeration of the curves form Table 2.

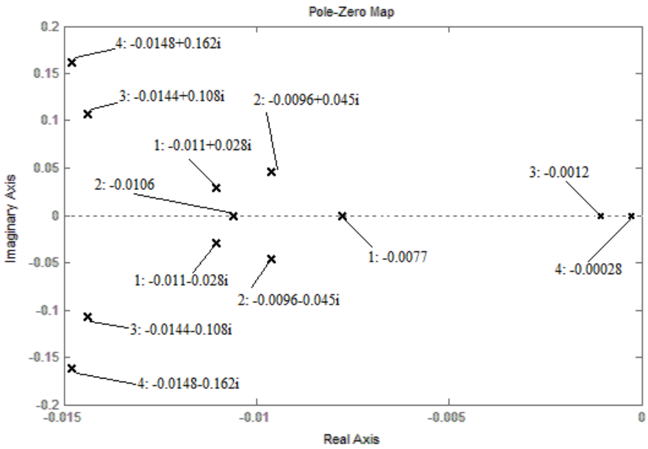

Figure 11. The poles distribution in complex plan of the control system.

Analyzing the poles distribution in the complex plane of the control system from figure 11 can be observed that in the case of tuning the PID controller by the maximum stability degree with iterations the system has the higher reserve stability with 4,2 times than the control system with PID controller tuned by the Ziegler-Nichols method.

From the calculation the values of the tuning parameters of the PID algorithm obtained by the maximum stability degree method with iterations and Ziegler-Nichols method, the parameters were settled in the industrial controller TRM-151 and were obtained the experimental curves of the system, figure 12: curve 1- in the case of tuning the PID controller by the maximum stability degree method with iterations, curve 2 - tuning the PID controller by the Ziegler-Nichols based on the step response. In the Table 3 are presented the performance of the control system for these two cases.

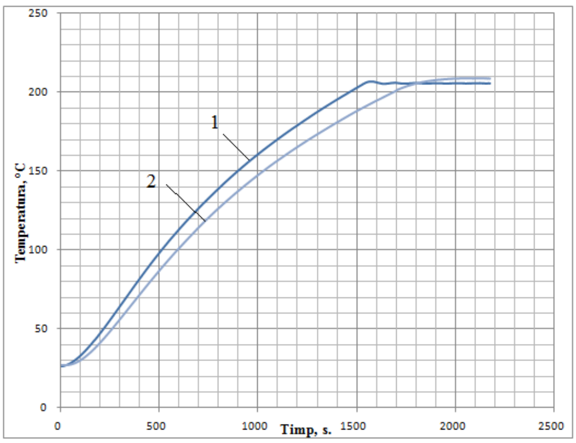

Figure 12. The transient experimental processes of the control system with PID.

Table 3. Performance of the control system.

Perform. of control system	**Nr. curve**	ε, %	t_c, s	σ, %	t_r, s	λ
Maxim. stabilit. degree method	1	5	1407	0	1407	0
Ziegler-Nichols	2	5	1625	0	1625	0

Analyzing the performance of the transient processes of the control system presented in the Table 3 can be observed that in the case of tuning the controller by the maximum stability degree method with iteration the settling time is lower with 14% than the control system with PID controller tuned by the Ziegler-Nichols method.

5. CONCLUSIONS

Analyzing the obtained results it can be done the following conclusions:

1. In the paper were compared the analytical and experimental methods of tuning the PID controller. As analytical method was chosen the maximum stability degree method and as the experimental method was chosen the Ziegler-Nichols method based on the step response.
2. There was designed the thermal control system in the electric oven, where the temperature control was realized by the industrial controller TRM-151, OWEN firm.
3. In case of using the analytical tuning method were used the identification procedures from the GUI System Identification Tool and was obtained the transfer function of the oven model with inertia second order and time delay.
4. To the identified model object was tuned the PID controller by the maximum stability degree method with iterations.
5. Based on the experimental transient process of the oven were obtained the tuning parameters of the PID controller by the Ziegler - Nichols method based on the step response.
6. From analyzing the performance of the control system with PID controller tuned by these methods, the best results were obtained for the case of tuning the PID controller by the maximum stability degree method with iterations.
7. The obtained results were verified by the

setting the tuning parameters in the industrial controller TRM-151. After, comparison of experimental results was observed that for the both methods were obtained the a periodical processes, without overshooting with stationary error equal with ±5%, but the transient process of the control system with PID controller tuned by the maximum stability degree method with iterations has the settling time lesser with 1,15 times than the system with PID controller tuned by the Ziegler-Nichols method based on the step response.

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