Greenhouse Temperature Control System

Irina COJUHARI, Bartolomeu IZVOREANU, Dumitru MORARU, Aurel SPEIAN, Alexei ROMANOV
Technical University of Moldova, Automatic and Informational Technologies Department,
Ştefan cel Mare av., 168, MD 2004, Chişinău, Republic of Moldova
irina.cojuhari@ati.utm.md, izvor@mail.utm.md, mitru3@mail.ru,
speian.aurel@gmail.com, lexusrv@gmail.com

***Abstract* — This paper proposes to control the temperature regime in the greenhouse using the universal controller OWEN TPM 151. The tuning controller was performed using the maximal stability degree method. As a result of this study, the algorithm of tuning controllers and the procedure of determining the system's performance in dependence of maximal stability value are proposed. The control object was identified using the System Identification Toolbox from MATLAB. The obtained results were compared with results obtained using the auto-tune regime from OWEN TPM 151 controller.**

***Index Terms* — the control of temperature regime, identification of control object, tuning controller, the maximal stability degree method.**

I. INTRODUCTION

The various technological processes need the control of temperature regime. The thermal processes represent the slow time-varying processes and they can be characterized with big inertia, in this case the tuning controllers can become a difficult procedure [1,6].

In the specialization literature many tuning methods of typical controllers are presented: the empirical methods based on the classical methods of finding the tuning parameters developed by Ziegler-Nichols, analytical methods, graph-analytical methods and methods based on the optimization techniques. A large class of these methods need the mathematical model of the technological process [2, 4, 5, 7].

Mathematical modeling of the technological process represents a difficult procedure and needs using the identification methods [3].

This paper proposes to control the temperature regime in the greenhouse, using the universal controller OWEN TPM 151. The OWEN TPM 151 controller is the universal controller with two canals of control, which allows to control the physical quantities of the technological process based on the PID control law, the tuning parameters can be installed manually or using the auto – tuning regime from the controller [11]. In this paper it was proposed to tune the controller using the maximal stability degree method to the model object that was identified using the parametric model ARX (Auto-Regressive eXogenous) from ARMAX (Auto-Regressive Moving Average with eXogenous inputs) class [3].

The maximal stability degree method (M.S.D.) is the grapho-analytical method which permits to obtain the high performance of the control system, the obtained results were compared with the results obtained in the case of tuning PID controller using the auto-tune regime from OWEN TPM 151 controller [3].

II. THE CONTROL OBJECT IDENTIFICATION

Schematic diagram of temperature control system is presented in the Figure 1, where 1 - is the greenhouse, 2 - heater, 3 - temperature transducer DTS-054, 4 - universal controller OWEN TPM 151.

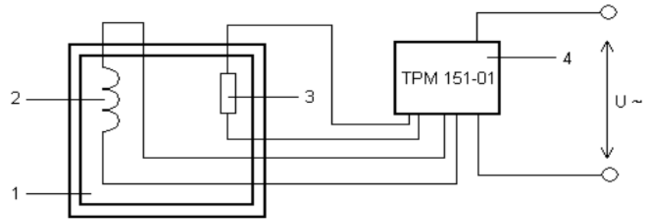


Fig. 1. Schematic diagram of temperature control system.

The proposed method of tuning controller is the graph-analytical method, used to make identification of the control object, using the parametric model ARX (relations (1)) [3]. The experimental curve of temperature variation is presented in the Figure 2, for this curve the identification was made.

$$A(q^{-1})y(t) = B(q^{-1})u(t-nk) + e(t), \qquad (1)$$

where $A(q^{-1}) = 1 + a_1 q^{-1} + a_2 q^{-2} + ... + a_{na} q^{-na}$,

$B(q^{-1}) = b_0 + b_1 q^{-1} + b_2 q^{-2} + ... + b_{nb} q^{-nb}$.

$y(t)$ - output signal;

$u(t-nk)$ - input signal;

nk - number of input samples that occur before the input affects the output, also called the dead time in the system;

$e(t)$ - disturbance signal;

q^{-1} - delay operator.

The vector of parameters which is estimated is presented in the follow relation

$$\theta = [a_1\, a_2 \ldots a_{na}\, b_1\, b_2 \ldots b_{nb}].$$

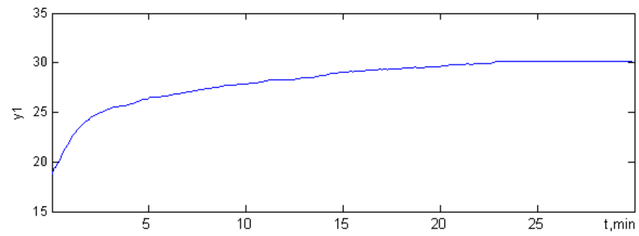


Fig. 2. The experimental curve.

Based on the obtained data from the experiment and using the System Identification Toolbox MATLAB, it was obtained the following transfer function in the operator q^{-1} of the control object

$$H(q^{-1}) = \frac{r_1 q^{-1} + r_2 q^{-2}}{1 - l_1 q^{-1} + l_2 q^{-2}} = \frac{0.2215q^{-1} + 0.2215q^{-2}}{1 - 1.384q^{-1} + 0.3989q^{-2}}. \quad (2)$$

The transfer function (2) in the Laplace transform is presented in relation (3).

$$H(s) = \frac{b_0 s + b_1}{a_0 s^2 + a_1 s + a_2} = \frac{-0.5149s + 67.9}{s^2 + 9.205s + 2.192}. \quad (3)$$

Next, it is proposed to tune the P, PI and PID controllers to the model object (3) using the maximal stability degree method in the graph-analytical form [8].

III. THE ALGORITHM OF TUNING CONTROLLERS

The structure scheme of the temperature control system is presented in the Figure 3, where $H_R(s)$ – represent the controller's transfer function and $H_{PF}(s)$ – the transfer function of the control object presented in relation (3).

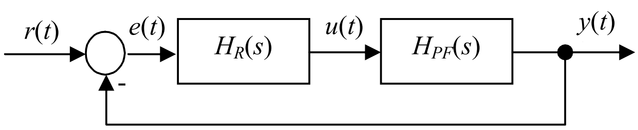


Fig. 3. Structure scheme of temperature control system.

P controller is tuned to the model object with transfer function (3) and applied M.S.D. method, the tuning parameters of controller are determined from relation [8, 9, 10]

$$k_p = \frac{-a_0 J^2 + a_1 J - a_2}{(b_1 - b_0 J)}. \quad (4)$$

In the relation (4) the J is the maximal stability degree which is chosen from the following condition $J>0$.

The tuning parameters of the PI controller are determined from relations [8, 9, 10]

$$k_p = \frac{d_0 J^3 - d_1 J^2 + d_2 J - d_3}{(b_1 - b_0 J)^2}, \quad (5)$$

where $d_0 = 2a_0 b_0$;

$d_2 = a_1 b_0 + 3a_0 b_1$;

$d_3 = 2a_1 b_1$;

$d_4 = a_2 b_1$,

$$k_i = \frac{a_0 J^3 - a_1 J^2 + a_2 J}{(b_1 - b_0 J)} + k_p J. \quad (6)$$

The tuning parameters of the PID controller are determined from relations [8, 9, 10]

$$k_d = \frac{-d_0 J^4 + d_1 J^3 - d_2 J^2 + d_3 J - d_4}{2(b_1 - b_0 J)^4}, \quad (7)$$

where $d_0 = 2a_0 b_0^3$;

$d_1 = 8a_0 b_0^2 b_1$;

$d_2 = 12a_0 b_0 b_1^2$;

$d_3 = 2a_2 b_1 b_0^2 - 2a_1 b_0 b_1^2 - 6a_0 b_1^3$;

$d_4 = -2a_1 b_1^3 + 2a_2 b_0 b_1^2$,

$$k_p = \frac{d_0 J^3 - d_1 J^2 + d_2 J - d_3}{(b_1 - b_0 J)^2} + 2k_d J, \quad (8)$$

where $d_0 = 2a_0 b_0$;

$d_2 = a_1 b_0 + 3a_0 b_1$;

$d_3 = 2a_1 b_1$;

$d_4 = a_2 b_1$,

$$k_i = \frac{a_0 J^3 - a_1 J^2 + a_2 J}{(b_1 - b_0 J)} - k_d J^2 + k_p J. \quad (9)$$

The tuning parameters of P, PI and PID controller - k_p, k_i and k_d are the function of known parametrs of control object (3) and of the unknown value J - stability degree of control system: $k_p=f(J)$, $k_i=f(J)$, $k_d=f(J)$ (see relations (4)-(9)). Based on these relations in the case of known object's parameters and in the case of variation stability degree $J \geq 0$ in the strict limits, the respective calculations were made and the dependences $k_p=f(J)$, $k_i=f(J)$, $k_d=f(J)$ for P, PI and PID controllers were obtained.

A simulation was made to verify the performance of the control system. If the performance doesn't satisfy the imposed performance, the iterative process will choose other sets of values of controllers parameters from curves $k_p=f(J)$, $k_i=f(J)$, $k_d=f(J)$, the procedure will be repeated until the performance of system will be satisfied.

IV. APLICATIONS AND COMPUTER SIMULATION

To show the efficiency of the proposed algorithm of tuning the typical controllers to the identified model object (3), the tuning values of the P, PI and PID controller were determined from relations (4)-(9). For every case it was presented the dependencies $k_p = f(J)$ (tuning the P controller, Figure 4), $k_p = f(J)$, $k_i = f(J)$ (tuning the PI controller, Figure 5) and $k_p = f(J)$, $k_i = f(J)$, $k_d = f(J)$ (tuning the PID controller, Figure 6).

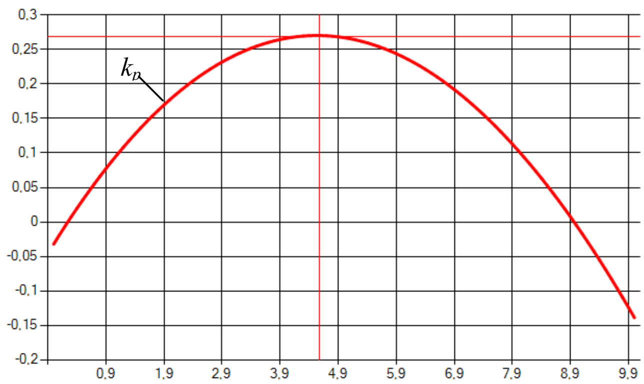


Fig. 4. Dependence $k_p = f(J)$, for P controller.

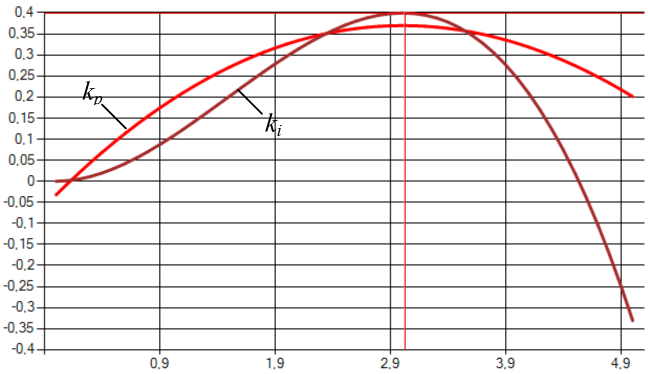


Fig. 5. Dependences $k_p = f(J),\ k_i = f(J)$, for PI controller.

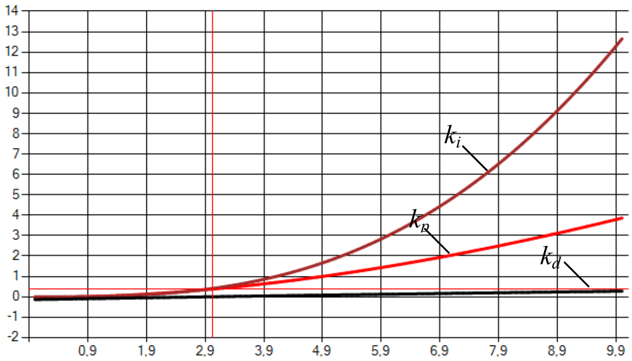


Fig. 6. Dependences $k_p = f(J),\ k_i = f(J),\ k_d = f(J)$, for PID controller.

From curves presented in the figures 4, 5, 6 were chosen the sets of tuning values for the case of tuning P, PI and PID controllers. The obtained sets of values J - k_p, k_i, k_d are presented in the Table I, the values obtained for the case 4 was obtained using the auto-tune regime of tuning PID controller from OWEN TPM 151 controller.

TABLE I. THE TUNING PARAMETERS OF P, PI, PID CONTROLLERS

Type of controller	Nr.	J	k_p	k_i	k_d
P controller	1	4,5	0,2703		
	2	3	0,2364		
	3	6	0,235		
PI controller	1	3	0,3696	0,399	
	2	2	0,3256	0,296	
	3	4,39	0,2867	0,0733	
PID controller	1	3	0,371	0,401	0,000221
	2	8	2,61	7,0028	0,204
	3	10	3,86	12,65	0,27
	4		0,93	1,19	0,0274

To verify the obtained results in case of tuning controllers P, PI and PID to the model object (3) using the M.S.D. a computer simulation of the control system was made in Simulink MATLAB. The simulation diagram of the control system is presented in the Figure 7.

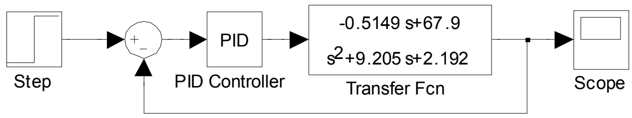
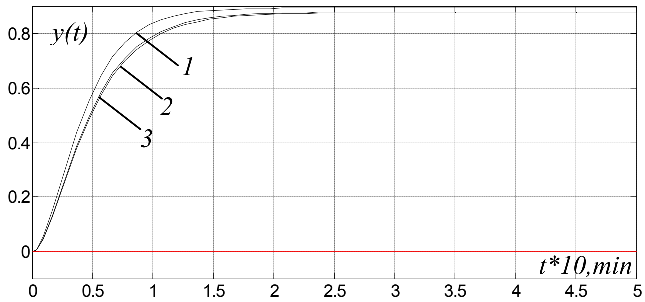
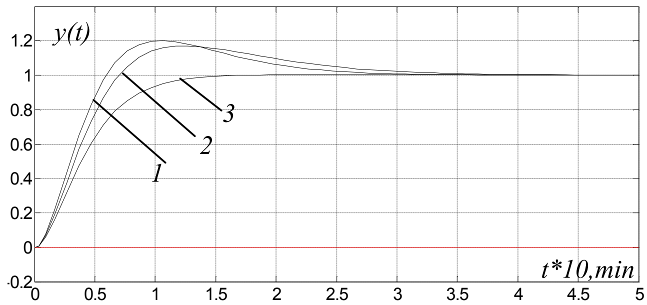


Fig. 7. Simulation diagrams of the control system.

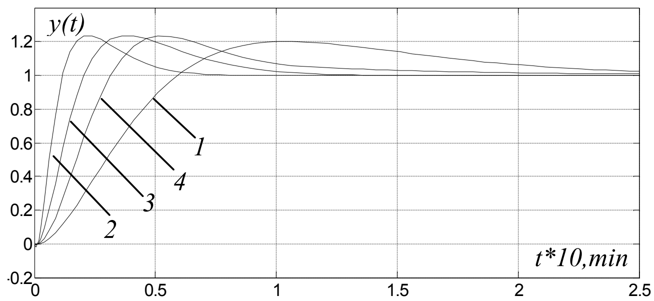
The obtained transition processes of the control system are presented in the Figure 8: *a*) transition processes with P controller; *b*) transition processes with PI controller; *c*) transition processes with PID controller. The number of curves from Figure 8 *a*, *b*, *c* correspond with numbers from Table I.



a) The transient processes of control system with P controller.



b) The transient processes of control system with PI controller.



c) The transient processes of control system with PID controller.

Fig. 8. The transient processes of the control system.

Figure 9 presents the distribution of dominants poles in the complex plan for the case of tuning PID controller using the M.S.D method and auto-tune regime from OWEN TPM 151 controller. The number of poles corespond with numbers from Table I.

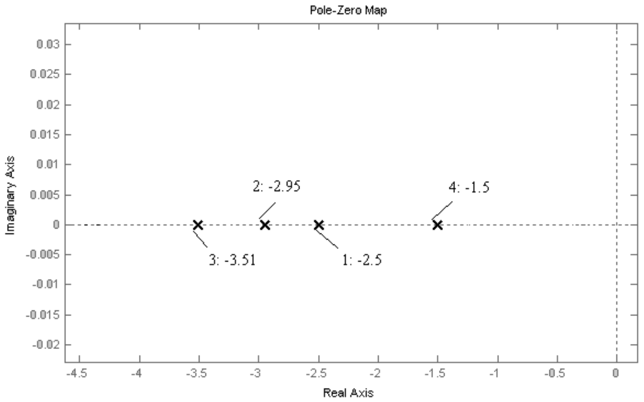


Fig. 9. Distribution of poles in the complex plan.

Analyzing the transient processes from Figure 8 *a*, *b*, *c,* it can be observed that the best results were obtained for the case of tuning PI controller using the maximal stability degree method (curves 3 from Figure 8, *b*), it was obtained the aperiodic process with control time equal with 13,5 minutes. For the case of tuning the PID controller using the auto-regime from OWEN TPM 151 it was obtained the transient process with overshoot equal 21 % and control time equal with 15 minutes. The transient processes obtained for the case of tuning PID controller using the maximal stability degree method have the overshoot equal with 21% and the control time smaller then the control time in case of tuning PID controller using the auto-regime from OWEN TPM 151.

Analyzing the distribution of poles in the complex plan from Figure 9, it can be observed that control system with PID controller tuning with M.S.D. method has the reserve of stability higher then control system with PID controller tuning use the auto-regime from OWEN TPM 151 (the number of poles correspond with numbers from Table I, for the case of tuning PID controller).

V. CONCLUSION

Analyzing the obtained results, the following conclusion can be made

1. The purpose of this paper was to tune the controller in the temperature control system using the universal controller OWEN TPM 151. The procedure of tuning was made using the M.S.D. method with iterations and the auto-tune regime from OWEN TPM 151.
2. The greenhouse was chosen as the control object and it was proposed to obtain the mathematical model using the procedure of identification. For identification, the ARX [2 2 1] model was used.
3. After tuning the P, PI and PID controller the best results were obtained for the case of tuning PI controller using the maximal stability degree method (curves 3 from Figure 8, *b*).
4. The maximal stability degree method is graph-analytical method which allows to obtain a wide range of tuning parameters and the iterative procedure allows to chose the parameters that would satisfy the performance of the control system.
5. Analyzing the distribution of poles in the complex plan for the case of tuning PID controller using M.S.D. method and auto-tune regime, it was observed that control system with PID controller tuning with M.S.D. method has the reserve of stability 6 times higher than control system with PID controller tuning using the auto-regime from OWEN TPM 151.

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