Implementation of Matlab-SIMULINK Based Real Time Temperature Control for Set Point Changes

Emine Dogru Bolat

Abstract—This paper presents Matlab-SIMULINK based real time temperature control of oven designed as an experiment set using different kinds of auto-tuning PID (Proportional-Integral-Derivative) methods. Ziegler Nichols Step Response Method (P,PI), Relay Tuning Method (P,PI) and Integral Square Time Error (ISTE) disturbance criterion (PI) method are used to control temperature of the experiment set. These methods are simulated using Matlab-SIMULINK software to define the controller parameters first. Afterwards, simulations are realized using these parameters. Finally, real time temperature control of the experiment set is implemented using the same parameters. And the results are discussed.

Keywords—Adaptive control, auto-tuning PID methods, real time control, temperature control

I. INTRODUCTION

Despite continual advances in control theory and the development of advanced control strategies, the proportional, integral and derivative (PID) control algorithm still finds wide application in industrial process control systems. It has been reported [1] that 98% of the control loops in pulp and paper industries are controlled by proportional-integral controllers. Moreover, as reported in [2], more than 95% of the controllers used in process control applications are of the PID type [3]. PID controllers have been used for industrial processes because of their simplicity and robustness. But it is difficult and time consuming to define the controller parameters accurately. Therefore, it becomes impracticable. So, auto-tuning techniques are developed to define these controller parameters. It has auto-tuning button and by means of this button PID parameters are computed and transferred to the controller. Thus PID controller has been faster, more practical and reliable [4]. Auto-tuning methods used in this study are Ziegler-Nichols Step Response, Relay and ISTE Tuning method. Because Matlab-SIMULINK based real time control is realized in this study, to control the temperature of the experiment set (oven) is more practical. To implement real time temperature control of the oven, a PIC based card is used. This card enables the real time temperature control of the oven through both PIC18F4585 and Matlab-SIMULINK. This card provides the communication between the oven and Matlab-SIMULINK simulation software through RS-232. Designed controllers using auto-tuning techniques are simulated in Matlab-SIMULINK by using mathematical model of the oven first. Then experiments through Matlab-SIMULINK and PIC based card are realized using the same controllers. Three different set point changes are applied for both simulations and experiments. Finally the results are discussed.

II. AUTO-TUNING TECHNIQUES

In this study, three kinds of auto-tuning methods are used. They are Ziegler-Nichols Step Response Method, Relay Tuning Method and ISTE Tuning Method. Ziegler-Nichols Step Response Method is based on transient response experiments. Many industrial processes have step responses of the type shown in Fig. 1 in which the step response is monotonous after an initial time.

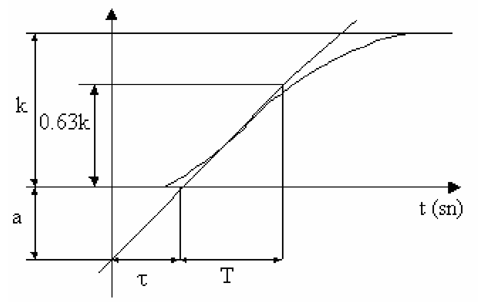

Fig. 1 unit step response of a typical industrial process [5]

$$G(s) = \frac{k}{1+sT}e^{-s\tau} \quad (1)$$

$$a = k\frac{\tau}{T} \quad (2)$$

A system with step response of the type shown in Fig. 1 can be approximated by the transfer function as in equation (1)

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where k is the static gain, τ is the apparent time delay, and T is the apparent time constant. The parameter *a* is given in equation (2) [5].

Closed loop control system with disturbance input is shown in Fig 2. G(s) is the transfer function of the plant and q(t) is disturbance input. The transfer function of the PID controller is given in equation (3).

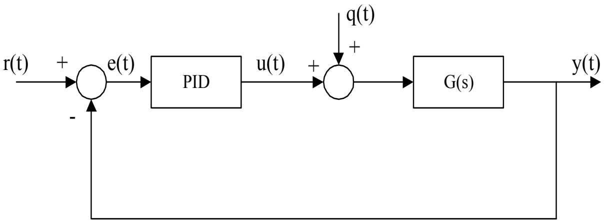

Fig. 2 closed loop control system with disturbance input [6]

A. The Ziegler-Nichols Step Response Method

A simple way to determine the parameters of a PID regulator based on step response data was developed by Ziegler and Nichols and published in 1942. The method uses only two of the parameters shown in Fig. 1, namely, a and τ. The regulator parameters are given in Table 1. The Ziegler-Nichols tuning rule was developed by empirical simulations of many different systems [5].

TABLE I
REGULATOR PARAMETERS OBTAINED BY THE ZIEGLER-NICHOLS STEP RESPONSE METHOD [5]

Controller	K_P	T_I	T_D
P	1/a	-	-
PI	0.9/a	3 τ	-
PID	1.2/a	2 τ	τ /2

B. Relay Tuning Method

The relay method is attractive since a control-relevant excitation signal is generated automatically, and many tuning rules exist to utilize the resulting process information [6,9]. The relay feedback is an efficient method of obtaining the critical point of a process with the critical point made available. PID types of controllers are easily tuned using classic Ziegler-Nichols rules and variants [6,10]. The arrangement for a relay feedback auto-tuner is shown in Fig. 3 [6,10]. The input and output signals obtained when the command signal r is zero are shown in Fig. 4.

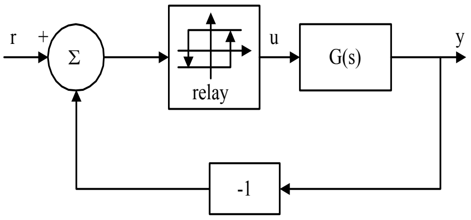

Fig. 3 block diagram of the relay auto-tuner [6, 7]

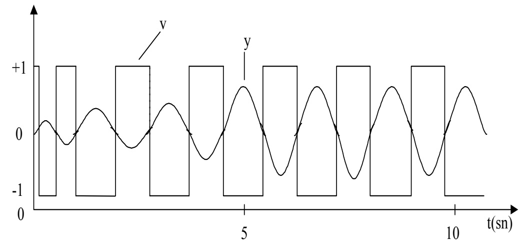

Fig. 4 linear system with relay control [6, 7]

The Fig. 4 shows that a limit cycle oscillation is established quite rapidly. The output is approximately sinusoidal, which means that the process attenuates the higher harmonics effectively. Let the amplitude of the square wave be d, then the fundamental component has the amplitude 4d/π. The process output is a sinusoidal with frequency ω_u and amplitude is shown as in equation (4).

$$a = \frac{4d}{\pi}\left|G(i\omega_u)\right| \tag{4}$$

To have an oscillation, the output must also go through zero when the relay switches. We can conclude that the frequency ω_u must be such that the process has a phase lag of 180^o. The conditions for oscillation are shown in equation (5).

$$\arg G(i\omega_u) = -\pi \text{ and } a = \frac{4d}{\pi}\left|G(i\omega_u)\right| \tag{5}$$

TABLE II
PID PARAMETERS USED IN TUNING METHOD [6, 7]

Controller	K_P	K_I	K_D
P	0.5 K_C	-	-
PI	0.4 K_C	1.25 / T_C	-
PID	0.6 K_C	2 / T_C	0.12T_C

K_c can be regarded as the equivalent gain of the relay for transmission of sinusoidal signals with amplitude a. This parameter is called ultimate gain. It is the gain that brings a system with transfer function G(s) to the stability boundary under pure proportional control. The period $T_c=2\pi/\omega_u$ is similarly called the ultimate period. The controller settings are given in Table 2. These parameters give a closed loop system with quite low damping. Systems with better damping can be obtained by slight modifications of numbers in the table. When a stable limit cycle is established, the PID parameters are computed, and the PID controller is then connected to the process [6,7].

C. ISTE Tuning Method

In recent years there has been much interest in the relay auto-tuning technique for determining the parameters of a PID controller. In this method, the PID controller is replaced by a relay so that the loop has a limit cycle. Tuning parameters of the controller are then calculated from measured values of the amplitude and frequency of the limit cycle. Here, we therefore define the formulate for the FOPDT (First Order Plus Dead Time) plant models which enable the optimum ISTE tuning parameters to be found from these measurements of the oscillation frequency and amplitude. The equations used in this method have been developed based on known critical point data, namely the critical frequency and critical gain. When performing relay auto-tuning, the approximate critical point data is found from the limit cycle data, namely the oscillation frequency ω_o and the peak amplitude a_o, which is used to calculate K_C, the approximate critical gain. K_C is found using the describing function for the relay, that is $K_C = 4d/a_o\pi$. For the FOPDT plant, the exact value of ω_o and K_C can be calculated using the Tsypkin method so that their relationship to ω_c and K_C can be found. It is therefore possible to obtain the above formulate in terms of the values of ω_o and K_C which will be found from the limit cycle measurement when using relay auto-tuning. The normalized gain is calculated by $\kappa_C = K * K_C$ [6,8]. These tuning equations for disturbance are seen in Table 3.

TABLE III

PI Tuning Formulae for ISTE Criterion [6, 8]

Controller	Disturbance criterion
K_P	$\dfrac{4.126\,\kappa_C - 2.610}{5.848\,\kappa_C - 1.06}\,K_C$
T_I	$\dfrac{5.352\,\kappa_C - 2.926}{5.539\,\kappa_C + 5.036}\,T_C$

III. Experimental Study

Fig. 5 shows the block diagram of the experiment set. PIC based card gets the temperature data by using the temperature sensor, thermocouple. PIC based card makes this data suitable and takes it to Matlab-SIMULINK environment through RS-232 serial connection. In Matlab-SIMULINK environment, this data is used to produce control signal. This control signal is applied to the oven through RS-232 serial connection and PIC based card. Debugger is used to program PIC microcontroller. It is practical to make experimental studies by using this experiment set. Because PIC based card enables the oven to be controlled by both Matlab-SIMULINK and PIC18F4585.

In Table 4, numbered parts of the oven shown in Fig. 6 are listed. In Fig. 5, PIC based card includes these hardware specifications: three temperature sensor inputs (0-1000 °C), two different independent phase controlled resistance supply outputs (40 + 40 Amper-rms), three different relay outputs (10 Amper-rms), RS-232 output (up to 256 Kbit) and microcontroller (PIC18F4585). PIC based card is composed of two basic parts. These parts are functionally different from each other and named as base card and microcontroller card. Microcontroller card contains PIC 18F4585, MAX232 and RJ MPLAB ICD2 connection. Microcontroller has 10MIPS processing speed. Base card has two main parts as sensor units and heater controller outputs [10].

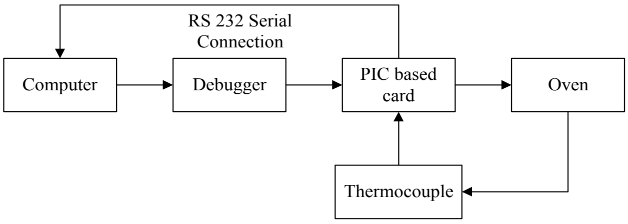

Fig. 5 block diagram of the experiment set

TABLE IV

Parts of the Oven Shown IN Fig. 6

1	Thermocouple (temperature sensor)
2	Oven
3	Fan
4	Two holes for disturbances

Fig. 6 experiment setup (oven and PIC based card)

The oven used in this study is a First Order Plus Dead Time (FOPDT) plant. An FOPDT system has a transfer function as in equation (1). In this equation, the parameters should be known are k, τ and T. These parameters are $k=106, \tau=64.14s$ and $T = 1494.7s$. Transfer function of the oven is given in equation (6) [10].

$$G(s) = \frac{106}{1495s+1} e^{-64,14s} \tag{6}$$

IV. SIMULATION AND EXPERIMENTAL RESULTS

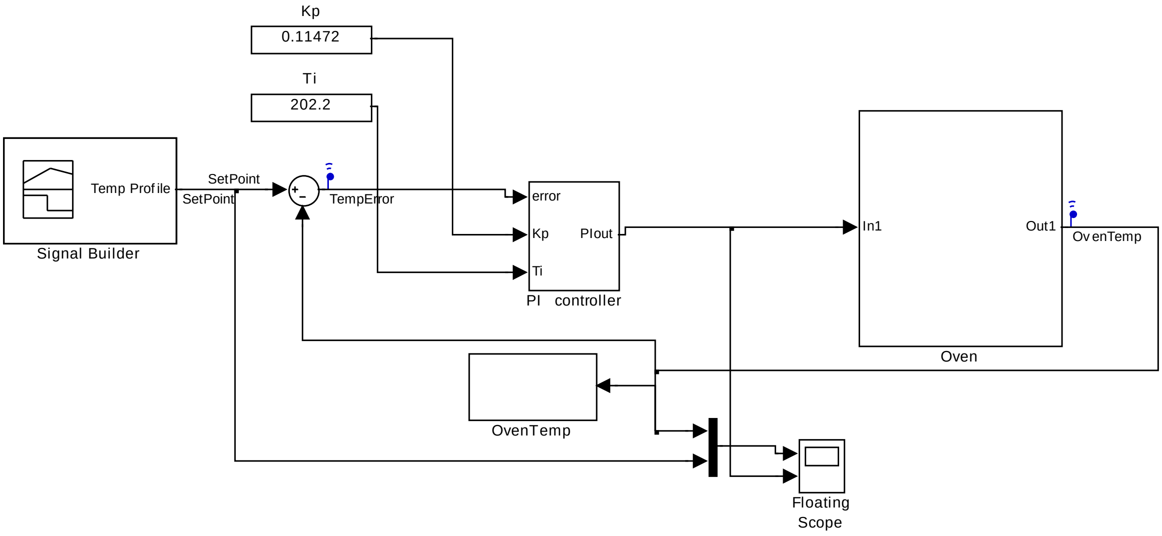

Fig. 7 simulink simulation diagram of the system

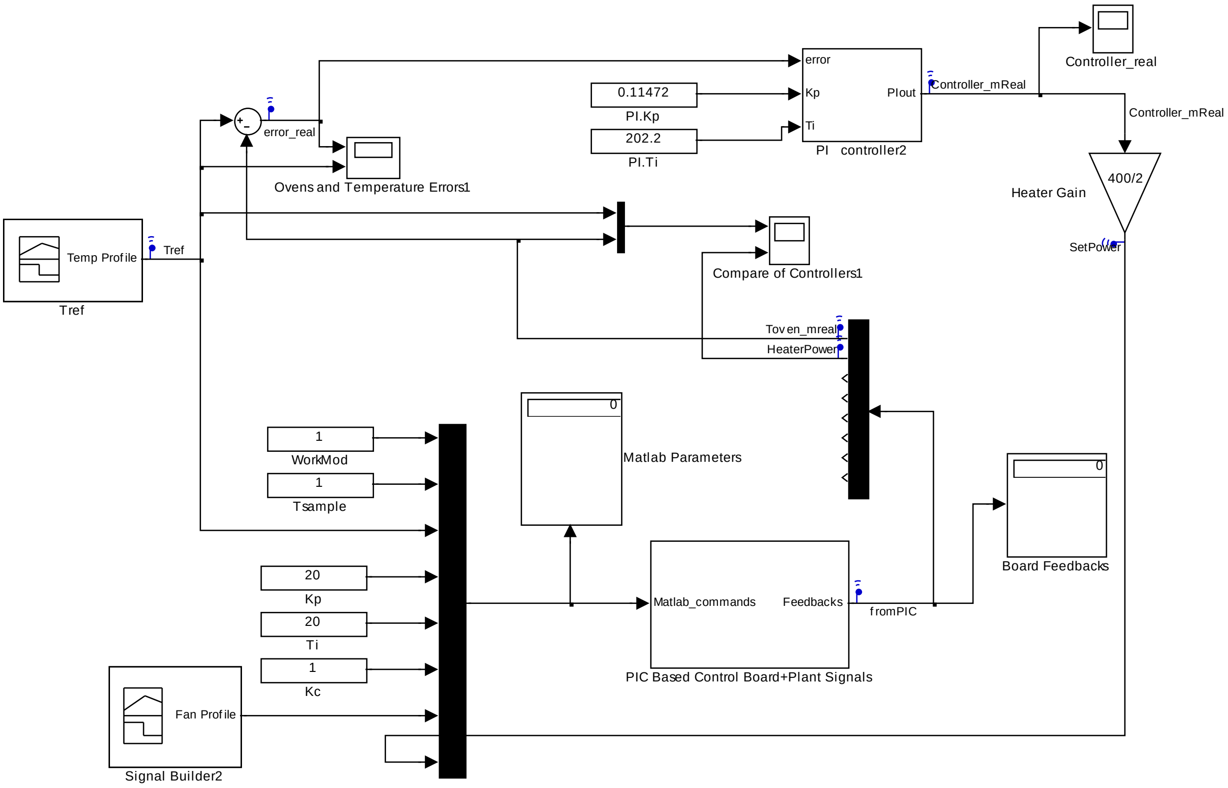

Fig. 8 simulink experimental block diagram of the system

Simulink simulation block diagram of the system is given in Fig. 7 while Simulink experimental block diagram of the system is seen in Fig. 8. In this section, the parameters of Ziegler-Nichols P, PI, Relay Tuning Method P, PI and ISTE Tuning Method PI (for disturbance input) are calculated first. To be able to define P and PI parameters of Ziegler-Nichols Step Response Method, step response of the oven was examined using the simulation block diagram in Fig 7. Simulation result of the open loop step response of the oven is seen in Fig. 9 a and τ parameters shown in Fig 1 are designated using this step response of the oven. To be able to calculate P and PI parameters of Relay and ISTE tuning methods, the oven was oscillated. Simulations of this oscillation and relay output are shown in Fig. 10 and Fig. 11 respectively. Calculated P and PI parameter for all types of tuning methods are given in Table 5. All tuning methods are simulated in Matlab-SIMULINK and implemented using both PIC based card and Matlab-SIMULINK for three set point changes. Three different set points as 80 ^{o}C, 100 ^{o}C and 120 ^{o}C are used in 5000 seconds. The second set point is changed 1520th second while the third set point is changed at 3120th second.

Simulation and experimental results are seen between Fig. 9 and Fig. 21. Settling time, settling temperature and ISE (the integral of the square of the error) of simulation and experimental results for all the methods used in this study are compared in Table 6 and Table 7 respectively. In Table 6, settling time of Relay Method P control is not written, because, the temperature of the oven can not reach to the settling temperature.

TABLE V

CALCULATED P AND PI PARAMETERS OF ALL AUTO-TUNING METHODS USED IN SIMULATIONS AND EXPERIMENTS

	Step P	Relay P	Step PI	Relay PI	ISTE Dist. PI
K_p	0.2199	0.1434	0.19792	0.11472	0.19932
T_I	-	-	192.4281	202.2	232.8609

As seen the figures between Fig. 12 and Fig. 21, simulation and experimental results are similar with each other. This means the model of the oven behaves as similar to the real oven. Naturally, the experimental graphical results are not as smooth as the simulation graphical results. Simulation and experimental results for P controller are seen Figure 12, 13, 14 and 15. As it is seen in these figures P control can not provide the output to reach to the settling temperature (offset occurs). As it is seen in Figure 16, 17, 18, 19, 20 and 21, PI controllers for three different methods achieve better responses. Among these PI controllers, Relay method PI controller gives the best response with 3214.05 s settling time, 8.9941e+006 ISE and 120 ^{o}C settling temperature for experimental results. It is the same for simulation results. Relay method PI controller enables the best performance with 3317.3 settling time, 8.9941e+006 ISE and 120 ^{o}C settling temperature in simulations.

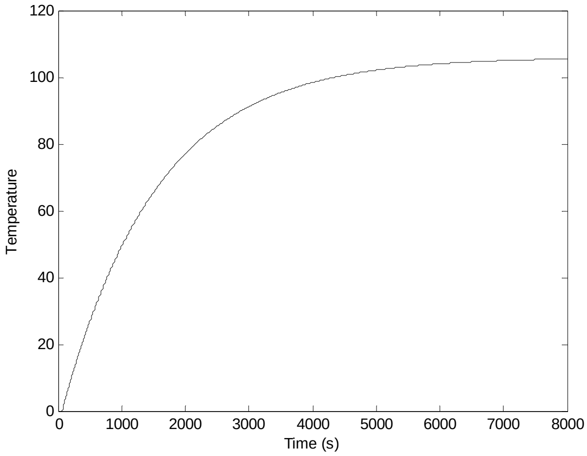

Fig. 9 simulation result of open loop step response of the oven

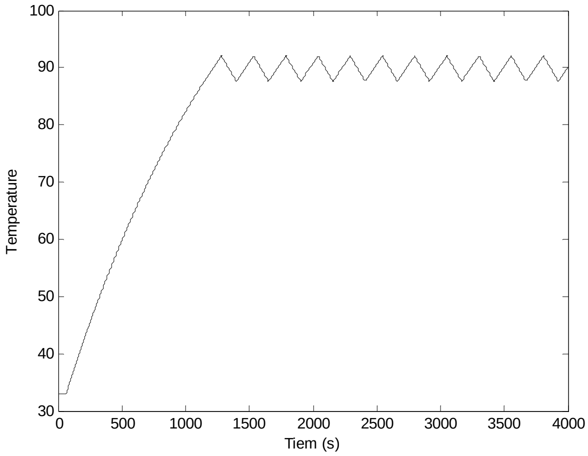

Fig. 10 simulation result of Relay tuning method of the oven

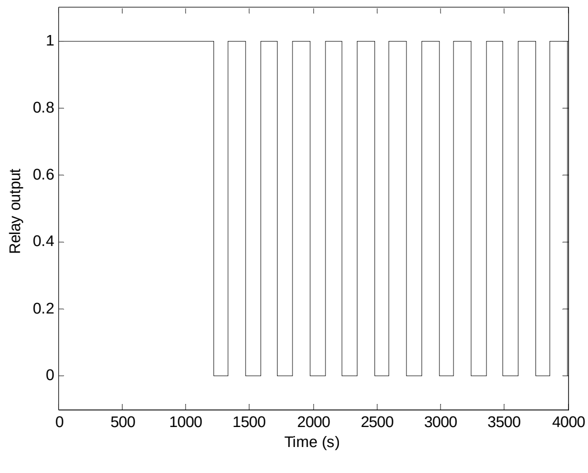

Fig. 11 simulation result of relay output

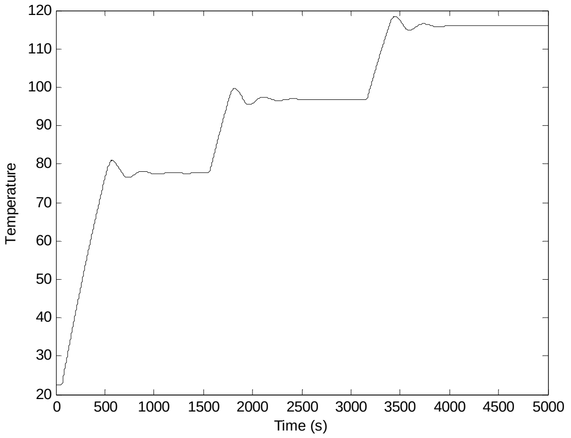

Fig 12 simulation result of P control for Ziegler-Nichols step response

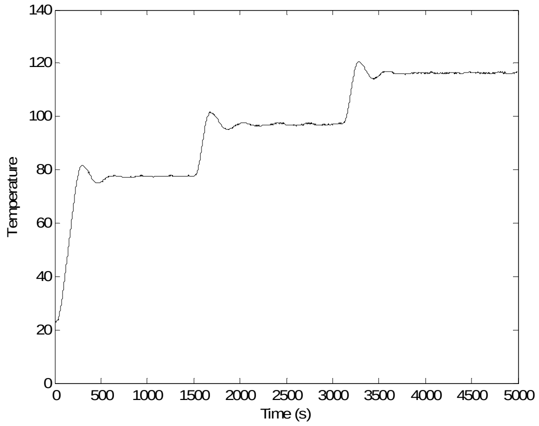

Fig. 15 experimental result of P control for the relay method

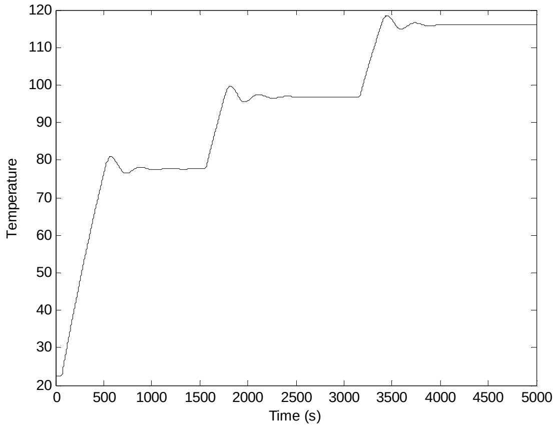

Fig. 13 experimental result of P control for Ziegler-Nichols step response

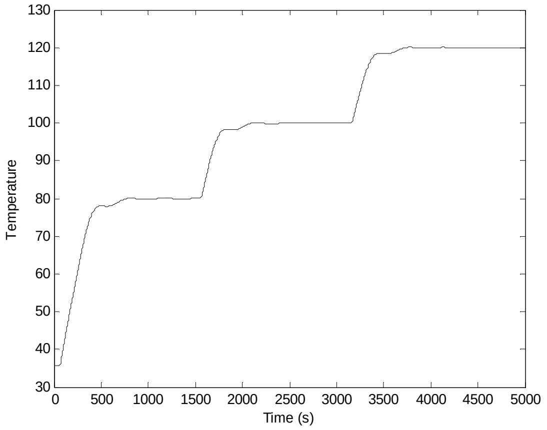

Fig. 16 simulation result of PI control for Ziegler-Nichols step response

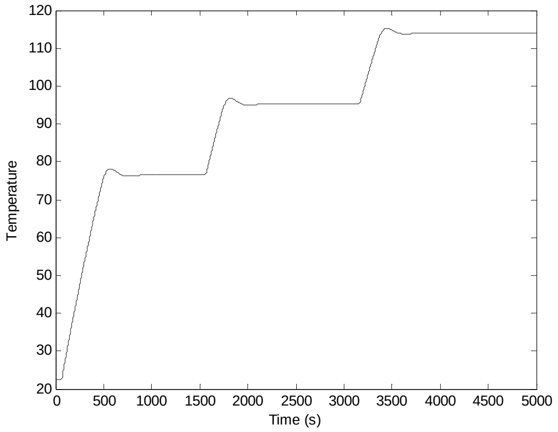

Fig. 14 simulation result of P control for the relay method

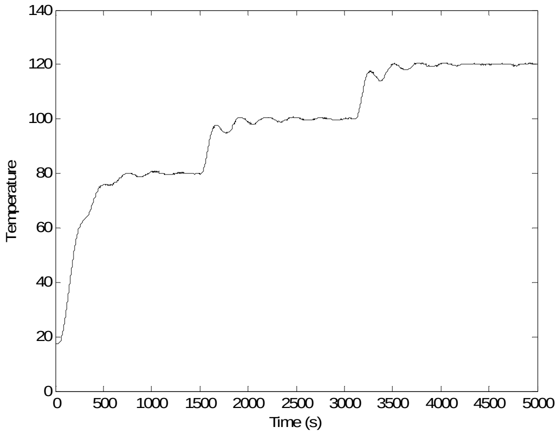

Fig. 17 experimental result of PI control for Ziegler-Nichols step response

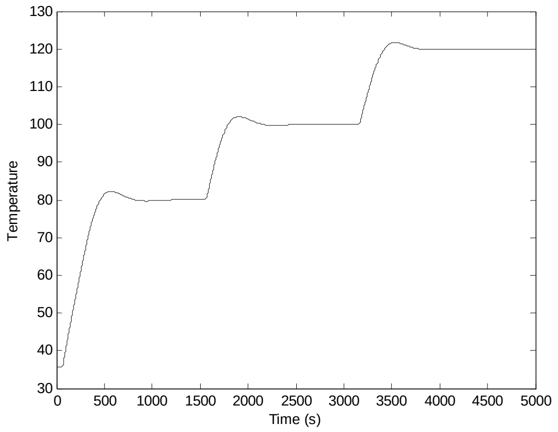

Fig. 18 simulation result of PI control the relay method

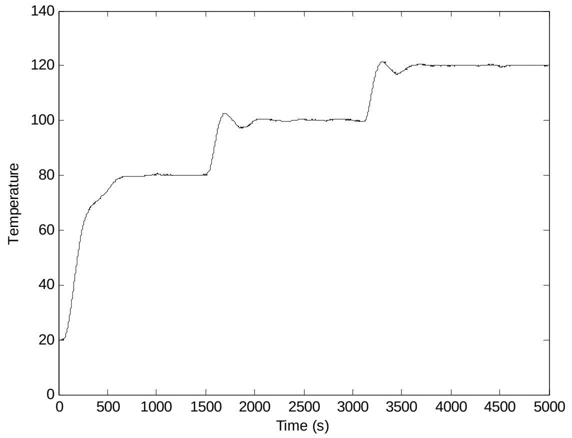

Fig. 19 experimental result of PI control for the relay method

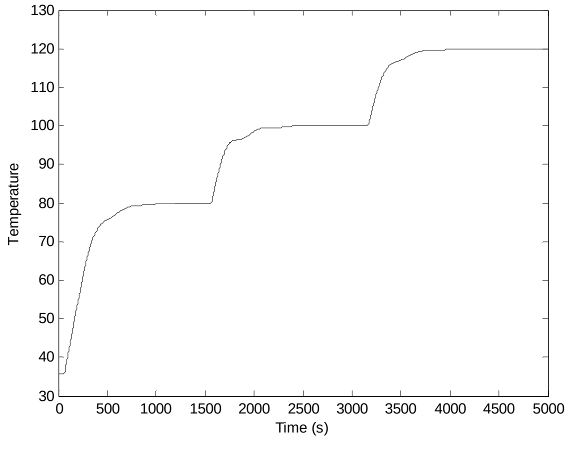

Fig. 20 simulation result of the ISTE disturbance criterion for PI control

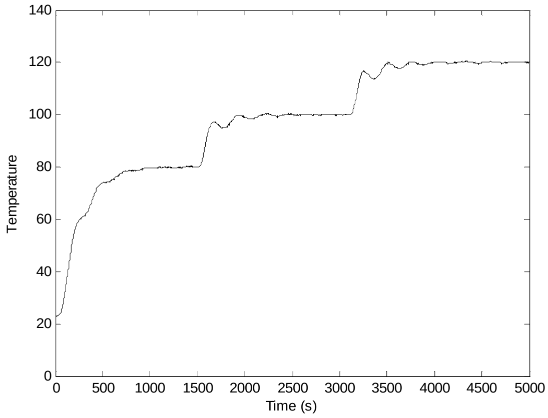

Fig. 21 experimental result of the ISTE disturbance criterion for PI control

TABLE VI
COMPARISON OF THE SIMULATION RESULTS
(ISE: THE INTEGRAL OF THE SQUARE OF THE ERROR)

Controller	Settl. time (s)	ISE	Settl. Temp. (°C)
Step P	3363	1.7741e+007	115.9
Relay P	-	1.9307e+007	113.9
Step PI	3318	9.0182e+006	119.9
Relay PI.	3317.3	8.9941e+006	120
ISTE Dist. PI	3335	9.2485e+006	119.9

TABLE VII
COMPARISON OF THE EXPERIMENTAL RESULTS
(ISE: THE INTEGRAL OF THE SQUARE OF THE ERROR)

Controller	Settl. time (s)	ISE	Settl. Temp. (°C)
Step P	3213.5	1.9755e+006	117.7
Relay P	3220	2.4723e+006	116.7
Step PI	3370.5	2.7450e+006	120.2
Relay PI.	3214.05	2.3936e+006	120
ISTE Dist. PI	3216.15	3.0249e+006	120

V. CONCLUSION

This paper presents Matlab-SIMULINK based real time temperature control of the oven for set point changes. A PIC based card is used between the oven and the computer (Matlab-SIMULINK) to provide their communication through RS-232. Ziegler-Nichols Step Response P, PI, Relay Tuning P, PI and ISTE disturbance criterion PI methods are used to control the oven. Three set point changes are applied as 80 °C, 100 °C and 120 °C. These methods are simulated first and implemented using Matlab-SIMULINK simulation software through PIC based card. Relay Method PI controller gives the best response among all the controllers for both simulations and experiments

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