Research on a PID Controller using PLC for a Heating System

Phuong Chi Nguyen [#1], Duc Quan Tran[#2]
Department of Automation, Faculty of Electrical Engineering, Thai Nguyen University of Technology, Vietnam.

Abstract—*This paper proposes a controller using an analog module of PLC for a heating system. The structure of the system includes a one-phase AC/AC converter, a heated resistance wire, a thermal sensor, an amplifier for a feedback signal and a cooling fan. Temperature of the heating wire is controlled by altering parameters of PID controller in a PLC module to vary its supply voltage. Finally, numerical and experimental results are illustrated to validatethe effectiveness of the proposed system.*

Keywords—*Heating system, PLC, PID controller in PLC, MATLAB-Simulink simulation, experimental test bench.*

I. Introduction

The demand for using and controlling heathas beenessential for many decades. In industry, heat is not only used for baking, drying, thermal treatment or melting metals but also for other special applications. Heatcan be generated from a variety of sources and electric power is one of them. Electric devices used to produce heatare environmentally friendly. They produce no noise and alsono gas emission. The use of a variable resistance heating element to monitor the temperature of work and control heat input to the element is described in[1]. The conversion from electricity into heat is conducted in many ways such as based on the Joule–Lenz law (applied for resistance furnaces, electrical stoves), arc discharge (in arc furnaces, electric welding) or Foucault eddy current influence (used in magnetic stoves) and so on. Authors in [2] propose a solution that is the use of PID Disturbance Observer (PID-DOB) method for resolving the unstable state of room temperature due to outside conditions.

In this paper, the proposed system is a heating chamber comprising of a resistance coil and control blocks. Heat is generated by the coil and controlled by adjusting its supply voltage.The system model is identified by using input and output signals. By this way, a PID controller embedded in PLCs is designed to control the heat of the chamber. Finally, the implementationis carried out withsimulationsand experiments to verify the usefulness of the proposed system, in which some parameters are varied to gain good results.

This paper is organized into several sections as follows: SectionII presents the identification processto obtain mathematical model of the heating system while Section III proposes a control method. Section IV and V show simulation and experimental results.

II. Model Of The Heated Object

In this study, the heating system is designed by Elettronica Venetanamely PU-1. The structure of this system consists of a heating chamber, a resistance coil, a thermal sensor, a voltage adapter AC/AC, a signal amplifier and a cooling fan as presented in Fig. 1. With real time applications, parameters of the object maychange,hence its transfer function is no longer accurate. Accordingly, it is necessary to determine the proposed object again. The identification process is performed through two steps: obtaining experimental data and recognizing the model by Toolbox Identification in MATLAB.

In order to estimate the model of the object, the resistance coil is supplied by an AC voltage source. Signals of coil voltage and chamber temperature (measured by the thermal sensor) are achieved by Arduino UNO. After that, these signals are sent to MATLAB/Simulink. Then, the mathematical model of heat object (so-called a transfer function describing approximately a real object) is determined by using Identification Toolbox in MATLAB[3, 4]. The principle scheme and data of voltage and temperature are shown in Figs. 2-3. From the input and output signals derived in Fig. 3, parameters of the estimated model of the system similar to the real system (the best fit is 95.23%)are shown in Figs. 4-5. The transfer function $W_r(s)$ of a resistance coil is written in (1).

$$W_r(s) = \frac{T(s)}{U(s)} = \frac{K}{1+\tau s} \tag{1}$$

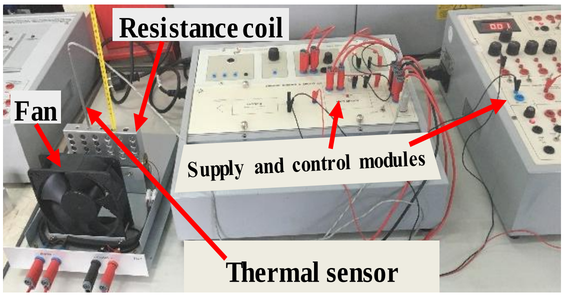

Fig 1: The experimental heating system

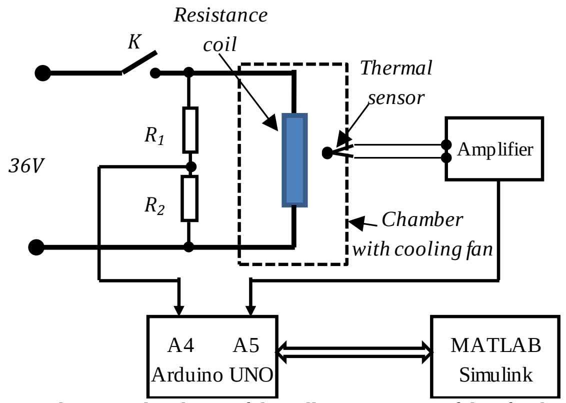

Fig 2: The principle scheme of the collecting process of data for the system identification.

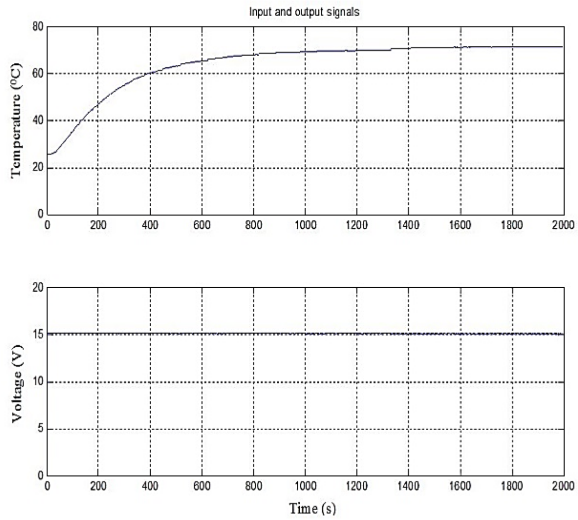

Fig 3: Input and output data for model identification

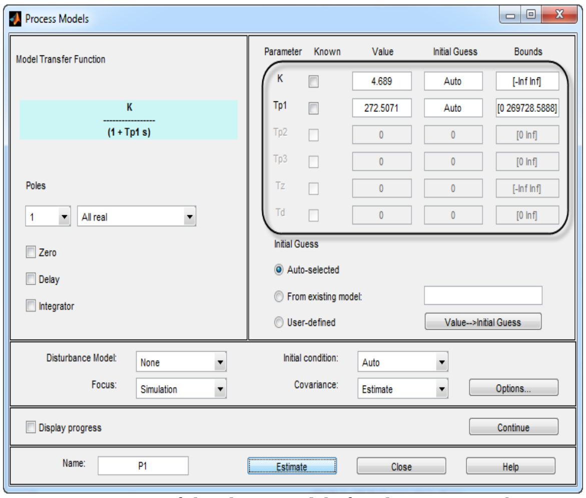

Fig 4: Parameters of the object model after the estimation by using MATLAB tool box

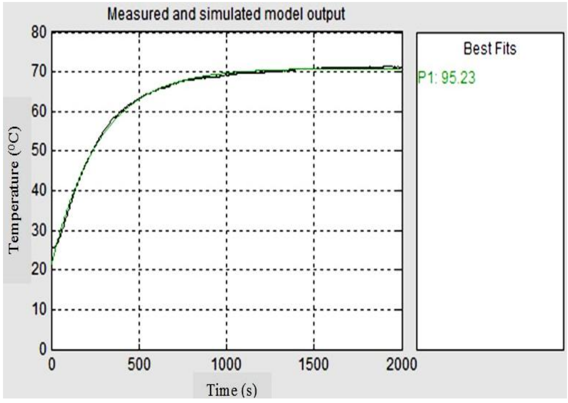

Fig 5: Response of the estimated system

where T(s) and U(s) are Laplace elements of temperature and input voltage of the resistance wire respectively; K and τ are the gain and time constant of the resistance wire respectively. From the estimation process, we have K = 4.689 and τ = 272.51s.Additionally, the temperature of the resistance coil is varied by altering the voltage of an AC-AC converter. Therefore, the transfer function of the converter can be expressed as follows:

$$W_b(s) = \frac{K_b}{1+\tau_b s} \quad (2)$$

$$\tau_b = \frac{1}{2mf} \quad (3)$$

$$K_b = \frac{V_{max}}{V_{min}} \quad (4)$$

where K_b represents the gain of the converter equal to the ratio of maximum and minimum voltages, τ_b is a time constant of the converter; m is the number of oscillations in one period of the power supply (m = 2); f isthe frequency of the supply voltage (f = 50Hz).

Thus, the transfer function of the AC-AC converter$W_b(s)$is written in (5).

$$W_b(s) = \frac{K_b}{1+\tau_b s} = \frac{3.6}{1+0.005s} \quad (5)$$

The proposed system includes a converter and the resistance coil connected in series. Eventually, the transfer function$G(s)$ of theheatingobject and converter is written in (6).

$$G(s) = W_b(s)W_r(s) = \frac{16.8804}{(1+0.005s)(1+272.51s)} \quad (6)$$

III. CONTROL METHOD

This paper applies a PID controller to the proposed heating system. This research aims at keeping the degree of the chamber temperature stable. The PID controller isdesigned to control the heat of the object by changing the supply voltage. Basically, PID controller is an abbreviation of three basic elements of a controller: Proportional transfer function (P), Integral transfer function (I) and Differential transfer function (D). There are three requirements of a controller which are working precision (P), accumulate experiences (I) and quick -response (D)[5].The close system is presented in Fig. 6 and PID controller is expressed as in (7-8).

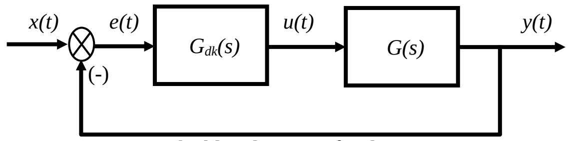

Fig 6: The blog diagram of a close system

$$u(t) = K_P\left[e(t) + \frac{1}{T_I}\int e(t)dt + T_D\frac{de(t)}{dt}\right] \tag{7}$$

$$G_{dk}(s) = \frac{U(s)}{E(s)} = K_P(1 + \frac{1}{T_I s} + T_D s) \tag{8}$$

where u(t) is the control output and e(t) is the error between reference x(t) and the object output y(t); $G_{dk}(s)$ is a transfer function of the controller; s is the Laplace operator.

Determination of parameters of the controller (K_P, T_I, T_D) results insignificant effects on the quality of the control system.From the previous section, the transfer function of the heating system$G(s)$is controlled by$G_{dk}(s)$. From Fig. 6, the requirement of the system is that output signal y(t) must track input signal x(t) properly with tiny overshoot in transient period and nullified error (e(t)=0) in steady state. Theoritically, if the whole system works perfectly, the transfer function of the close system$G_k(s)$ should satisfy (9).

$$G_k(s) = \frac{G_{dk}(s).G(s)}{1+G_{dk}(s).G(s)} = 1 \tag{9}$$

From (9), the controller$G_{dk}(s)$ of the system is determined as in (10).

$$G_{dk}(s) = \frac{1}{G(s).2\tau_{dk}s.(1+\tau_{dk}s)} \tag{10}$$

where $G(s)$ is the transfer function of the heating object and converter determined in (6); $\tau_{dk}$is a time constant of the controller.

IV. SIMULATION RESULTS

The estimated model and controller have been introduced in the previous sections. The block diagram is presented in Fig. 7. Prameters of the object are shown in equation (6) and the time constantτ_{dk} of the controller (10) isestimated to be0.005s by using the optimal module method[4, 5].Control signal and the response of temperature are illustrated in Figs. 8-9.It can be seen that the result of temperature control is quite good with an overshoot of 4.0% and a settling time of 0.004s. However, control voltage in the transient period is too high at about 120000V, which leads to ruining electric and electronics elements in the real system.Therefore, in order to deal with this issue, a block limiting control voltage 0-10V is inserted in the structure of system as shown in Fig. 10.

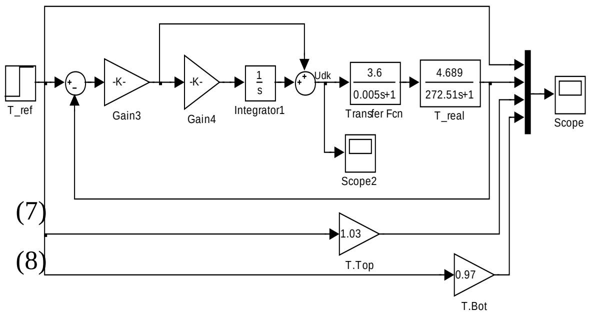

Fig 7: The block diagram of a system using PI controller

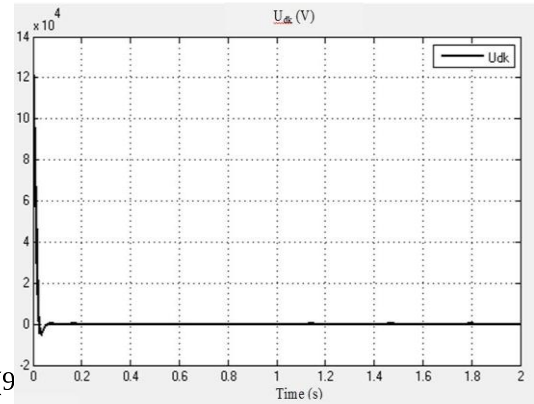

Fig 8:The characteristic of the control voltage

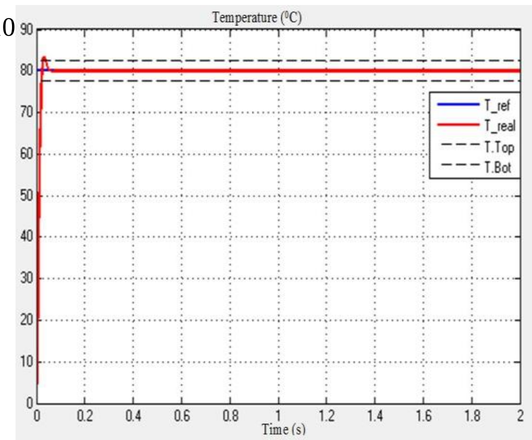

Fig 9: Temperature of the system according to optimal module method

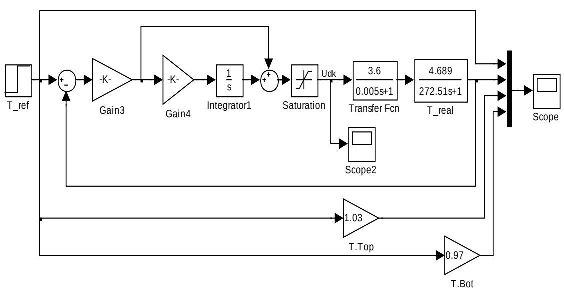

Fig 10: The block diagram of the system using a saturation block

V. EXPERIMENTAL RESULTS

In this section, a Programmanme Logic Controller (PLC)includinga PID controller for the heating system isapplied to control the experimental system (PU-1 by Elettronica Veneta in Fig. 1).The structure of the PID controller in PLC S7-200 is illustrated in Fig. 11 whereparameters from VD100 to VD116 are real double word variables located in the memory of PLC;Sp and Pv are setpoint and temperature of the system respectively; A/D and D/A are signal converters[6]. Fig. 12 presents a simple program of the system usingPLC ladder logicstructure.

A. The response of the system with step function input

The value of reference temperature is built by a step waveform with a steady value T_{ref} = 120^0C. The response of the experimental system is shown in Fig. 13. It can be seen that the overshoot is approximately 7.0% and the settling time is about 480s. The quality of this response is worse than that of the simulation due to the existing differences between the identified sytem and the real system. Therefore, the parameters of the controller as shown in (10) should be re-estimated with K_P = 1612.6275 and T_i = 268.025. The performance of the new controller is illustrated in Fig. 14. It is clear that temperature response of the system is improved with a tiny overshoot and a settling time of 300s.

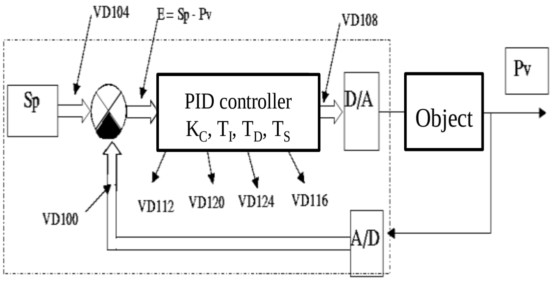

Fig 11:The structure of PID controller in PLC S7-200

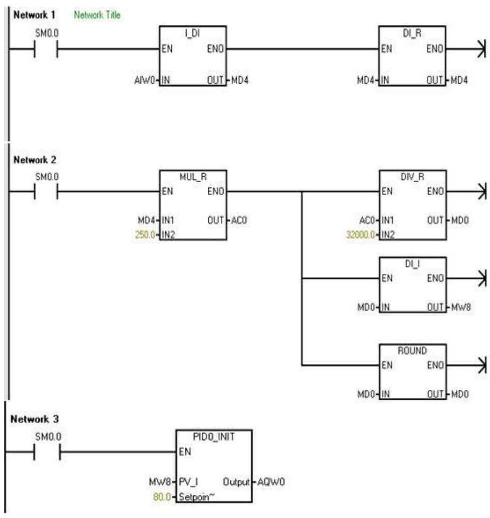

Fig 12:The control program designed in PLC S7-200

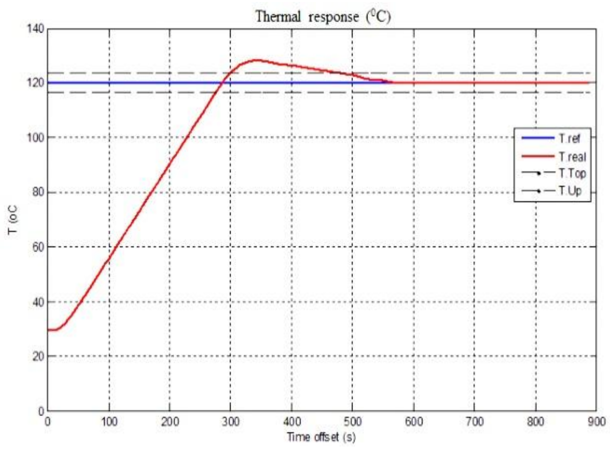

Fig 13: The thermal response of the system with afixed temperature reference

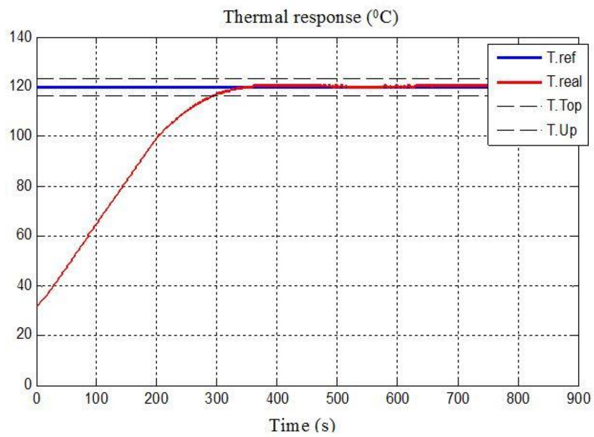

Fig 14: The updated thermal response of the system with a fixed temperature reference

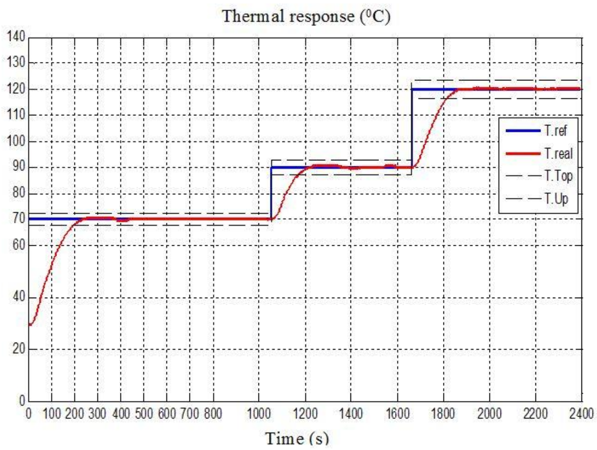

Fig 15: The thermal response of the system with variable temperature references

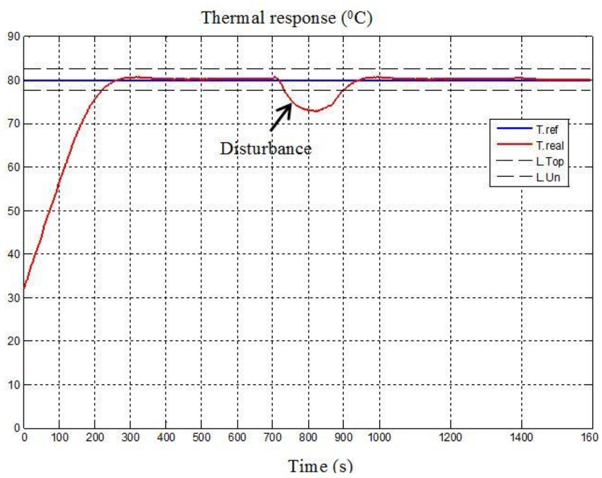

Fig 16: The thermal response with existence of disturbance

B. The response of the system with dynamic references

When the value of temperaturereferenceschanges from 70 to 90 and then 120 degree Celcius, the traction of the output signal is still respected with minor overshoots, minor errors and acceptable settling times as shown in Fig. 15.

C. The response with an existence of disturbances

Thetemperature reference is fixed at 80^0C. The disturbance is imposed to the system at 700s by turning on the cooling fan (Fig. 1). The responding characteristic of the system is shown in Fig. 16.

Nearly 200s after the impact of the disturbance on the system, the temperature error between the reference value and the output of the heating system is nullified to meet the control requirements.

VI. CONCLUSIONS

In this paper, a controlled heating system is proposed. An identification system is applied to obtain the mathematical model of the heating system. The PID controller is estimated to change supply voltage of the resistance coil to control the temperature of the heating chamber. Simulation and experimental results have validated performances and effectiveness of the proposed system. In the future, the system can be applied to control temperature according to technical requirements of a specific application in reality.

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