# Design a Temperature Control System Using Halogen Lamp

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# Design a temperature control system using halogen lamp

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**Abstract.** In this paper, a temperature control system based on Halogen lamp is designed for education and training purpose, which is low cost, energy saving and less time consuming for student's experimental task. The designed system consists of a box made of plastic and aluminum, a 300W Halogen lamp, a temperature sensor, an Arduino Uno R3 based microprocessor, a triac BT137-600E by NXP Semiconductors and 220V-50Hz power supply. First, a transfer function from power to temperature is obtained through system identification based on a unit step response. Then, a PID controller is designed for the temperature. Finally, the temperature control system is verified through experimental tests. The results show that the temperature converges to the set-point with short settling time and small overshoot. The average time period for doing system identification and real-time control is quite small for student analyzing and performing experimental tasks. Moreover, since the cost of the designed system is cheap, it is possible to provide a system to each student for experiments. In addition, it can be also used as a testbed for verifying new control algorithms.

**Keywords:** Temperature control · PID · System Identification.

## 1 Introduction

For education and training purpose, it is necessary to have a real-time control system for supporting students to do experimental tasks such as system identification, controller design, and have experience of real-time control. One example of benchmark systems in industrial processes is a temperature control system, for example, temperature control in thermal power plants, heating system in steel factories and oil refine factories. In laboratories, most of temperature control systems [1], [2] were built using resistors, which consume a lot of energy and time, and have high cost. This motivates us to design a temperature control system using classical PID controller [3], [4], which is low cost, time and energy saving for education and training purpose. There are several options for running experiments of the temperature control system: 1) the PID controller is installed on the microprocessor; 2) the PID controller is carried out using Matlab/Simulink; and 3) the PID controller is run on a designed software, which is based on C/C++ programming languages. All the information about the control system such as temperature, control signal, set point and PID parameter can be seen on a display screen. Thus, it will be easier for students to tune PID parameters and collect data for writing reports. In this paper, the first option will be presented. The remaining part of the work is organized as follows. In the next section, a temperature control system is designed. In Section III, the temperature system is identified. In Section IV, a PID controller is designed for the temperature system and some experiments are carried out. The final section gives conclusions and future works.


**Fig. 1.** Inside the kiln

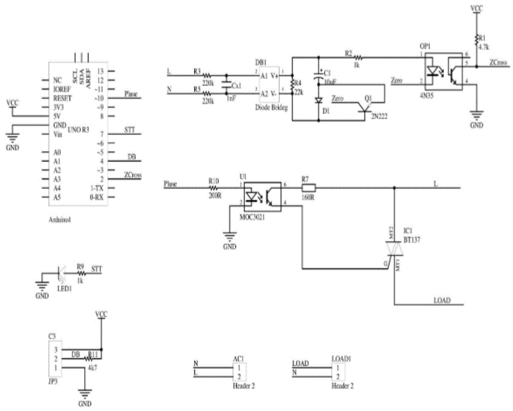

**Fig. 2.** Circuit diagram

## 2 Temperature control system

A temperature control system is designed including a heating furnace based on Halogen lamp, a temperature sensor, a triac working as actuator, and a PID controller which can be implemented on microprocessor or computer. A kiln is designed and made of aluminum frame and plastic-aluminum wall, which has a size of 32cm×24cm×24cm (length, width and height). Fig. 1 shows a picture inside the kiln, in which there are a Halogen lamp with 300W power and a temperature sensor DS18B20. The sensor can measure a range of temperature from −55 ºC to 125 ºC (see [5] for more information). A circuit diagram is designed as shown in Fig. 2, which contains an Arduino UNO R3, a triac BT173 [6], an opto-isolator MOC3021 [7], an opto-coupler 4N35 [8], a diode bridge and other elements such as resistors, capacitors, transistors, headers, LED and a DC supply. The circuit mainly perform tasks such as detecting zero cross and controlling the gate of triac to adjust the current through the lamp. By changing the triac current, the temperature of the furnace will be varied correspondingly.

## 3 System identification for the furnace

In order to determine the transfer function of the furnace, a step response is obtained as shown in Fig. 3, where the input has type of step function with amplitude of 50% of the maximum power and the sampling time is $T_s = 0.64$ second. For experiments, students may use a high-order transfer function with delay to model the furnace. In this design, the furnace is modelled as a first-order system plus time delay. From the step response of the kiln, it can be seen that there is no delay at all. This can be explained that the sensor is placed quite close to the Halogen lamp. Thus, the delay can be created by moving the sensor far away from the lamp or putting a small wall to separate the sensor and the lamp. Based on the step response in Fig. 3 and using System Identification Toolbox in Matlab, the transfer function is obtained as follows.

$$P(s) = \frac{k}{T_p s + 1} \tag{1}$$

in which $k = 155.9$, $T_p = 179.2$, and $\tau = 0$. The transfer function takes power applied to the kiln as input, and temperature from the sensor as output. It will be used for PID controller design later. For training purposes, one may use other methods for system identification.

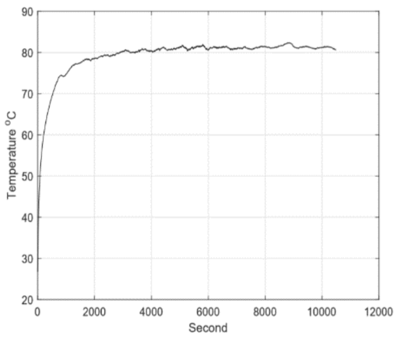


**Fig. 3.** Step response of the furnace

## 4 PID controller design

In this section, a PID controller is designed for the furnace. There are abundant methods [9-11] to tune PID controller. For simplicity, the PIDtuner of Matlab will be used to initially determine the PID parameter. This method is used as a baseline method to compare with other methods such as genetic algorithm, experimental tuning method [12] and others. The PID controller is designed as follows

$$R(s) = K_p + \frac{K_i}{s} + K_d s \tag{2}$$

where $K_p = 1.12$, $K_i = 0.02$ and $K_d = 0$. Then, the controller is converted into discrete-time one as follows by using trapezoidal approximation for the integral and second-order approximation for the derivative

$$u_k = u_{k-1} + a_0 e_k + a_1 e_{k-1} + a_2 e_{k-2} \tag{3}$$

in which $a_0 = K_p + \frac{K_i T}{2} + K_d T$, $a_1 = K_p + \frac{K_i T}{2} - 2K_d/T$, $a_2 = K_d/T$, and the sampling time for the controller is T = 0.69 second. This controller will be programmed for the microprocessor. The derived digital PID controller (3) will be veried through practical tests. Fig. 4 shows one of real-time control tests, where the measured temperature is on the right hand side and the control signal (power in percentage) is on the left hand side. Both the settling time and overshoot are small, they are 600 seconds and 1%, respectively. It means the designed temperature control system is stable as expected. This confirms that the obtained transfer function (1) is suitable and exact enough for controller design.

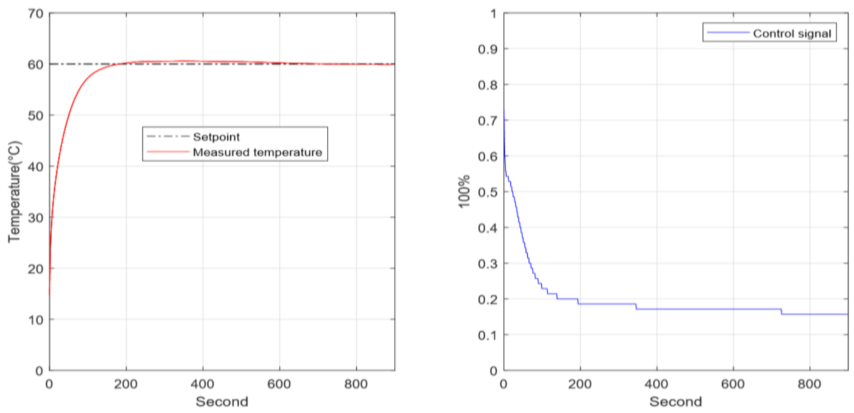


**Fig. 4.** Measured temperature and power under real time control test

## 5 Conclusions

In this work, a temperature control system for education and training purpose was designed. It consists of a microprocessor or computer based PID controller, a Halogen lamp based heating furnace, a temperature sensor and a triac for regulating the temperature. The temperature system was identified as a first-order system with zero time-delay using the System Identification Toolbox of Matlab. Then, the parameters of PID controller was obtained using the PIDtuner, and the controller was converted in to digital version for programming. Some experimental tests were carried out to verify the proposed system. The results show that the proposed system works stably, can be modified to have different models, and has low cost, better time and energy saving in comparison with the resistant heating furnace [1,2]. Thus, it is potential to apply for education and training purpose in areas of automation and control, and related fields with low cost, time and energy saving.

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