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Design of Heating System Controlled by Arduino

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Abstract

Temperature control of systems has become an important subject in all areas around us, especially, in industrial areas at wide range of operating temperature. Another important field is the identification of material characteristics. In this paper, a design of temperature controlled heating system is presented for a tension-compression testing machine. The system involves basically an isolated box, dry resistance, voltage regulator, thermocouple, air fun, microcontroller and computer. The temperature inside the box is controlled by a feedback controller. This feedback control system measures the temperature via a K-type thermocouple and uses a PID controller to compensate the errors. The Arduino board is used as microcontroller because it is cheaper, simpler and easier to programme. In this study, after doing some experiments, the user defined reference temperature profiles are accomplished on the test machine and are compared with that of the mathematical modeling of the heating system.

Key words: Heating system, Temperature control, PID, Arduino.

1. Introduction

The temperature control of a heating system is needed at many industrial fields such as food, production and metal industries. Besides, the control at the wide temperature range is very important in the science field. In literature, there are many studies on the temperature control of buildings [1-2]. These studies involve the modeling and control of the systems approximately at ambient temperature. They are related to the temperature control in the lower ranges. On the other hand, the applications with higher working temperatures can be appeared on the studies concerned some heating system such as ovens, furnaces etc. Ryckaert et al. present a paper on improving the performance of an oven by some advanced control algorithms [3] while Srisertpol et al. study electromagnetic ovens to heat the devices in the electronic manufacturing processes [4]. In another study, a temperature control system of a steel heat furnace is designed based on a model free control theory with PLC (Programmable Logic Control) control [5].

The dynamic behavior of a system should be derived for design and control of heating systems. To define the system parameters, the different identification procedures are advised. For the dynamic behavior, the process reaction curve is suggested to determine the parameters of the first order model with the dead time [6]. This is a graphical method and very useful for experimental

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studies. Bolat used this model for the temperature control of an oven with the different set point chances in the real time [7]. Elmadssia et al. tried to stabilize the system by using PI controller [8]. The system is modeled as a first order with the time delay which is a second order approximation.

The main methods such as PID (Proportional Integral Derivative), neural network, fuzzy-logic are presented for the temperature control of heating systems. PID controller is commonly used due to its simplicity and efficiency. The researchers studied on a new type of PID controller whose parameters are regulated automatically by fuzzy self-tuning [9]. In the industrial processes, Ding et al. studied the programmable logic controller (PLC) which is an industrial control computer for the temperature control [10]. The system has a PID based controller and also has good stability, high reliability and broad application prospects.

For high efficient temperature control systems, microcontroller and feedback controller are necessary. In this way, the desired temperature profiles can be achieved. As a new trend, ARDUINO microcontroller is introduced for simple applications since it is cheaper, simpler and easier to programme and it is also an open source microcontroller. Many researchers start to use this device widely. For example, Krishnamurthi et al. used Arduino for recording and monitoring real weather conditions such as temperature, humidity etc. in real time [11]. In another study, a low-cost temperature acquisition for incubator system was presented based on the Arduino board. A design of measurement and calibration system for K-type thermocouple was presented to study the temperature measurements sensitively [12].

Generally, the mechanical characteristics of materials are defined with mechanical experiments done at the ambient temperature. However, many applications concerned with heating processes take place at higher temperature values. In this study, a temperature controlled heating system is designed for a tension and compression testing machine. With this system designed, the experiments can be done at user defined temperature profiles with higher temperatures, for example, 400ºC. The feedback system with PID controller can control the temperature by using ARDUINO microcontroller. Firstly, the system has been modeled as a first order with time delay. Then, the necessary system devices are assembled and the software is written on MATLAB to control the system. With the experiments, the temperature control is performed successfully and the desired results with the assigned coefficients of the controller are achieved compared to the theoretical ones.

2. Description of the Setup

The scheme of the setup which allows carrying out the tension and compression tests at desired temperature profile has been shown in Fig. 1. In this system, the heat source is a dry resistance with a power of 2.5 kW. The inner temperature of the isolated box is adjusted by regulating the voltage on the dry resistance. The resistance power can be regulated between 0-2.5 kW. Here, the voltage adjustment is done by using 0-5 V DC input. The ELCON Power Regulator shown in Fig. 2 is used to produce the desired AC voltage between %0 - %100 (0-220V) according the DC supply generated via ARDUINO card used as a microcontroller. Arduino can control the AC voltage with the output PWM signal which is between 0 – 5V DC. In this feedback temperature control system, the inner temperature is measured as an output.

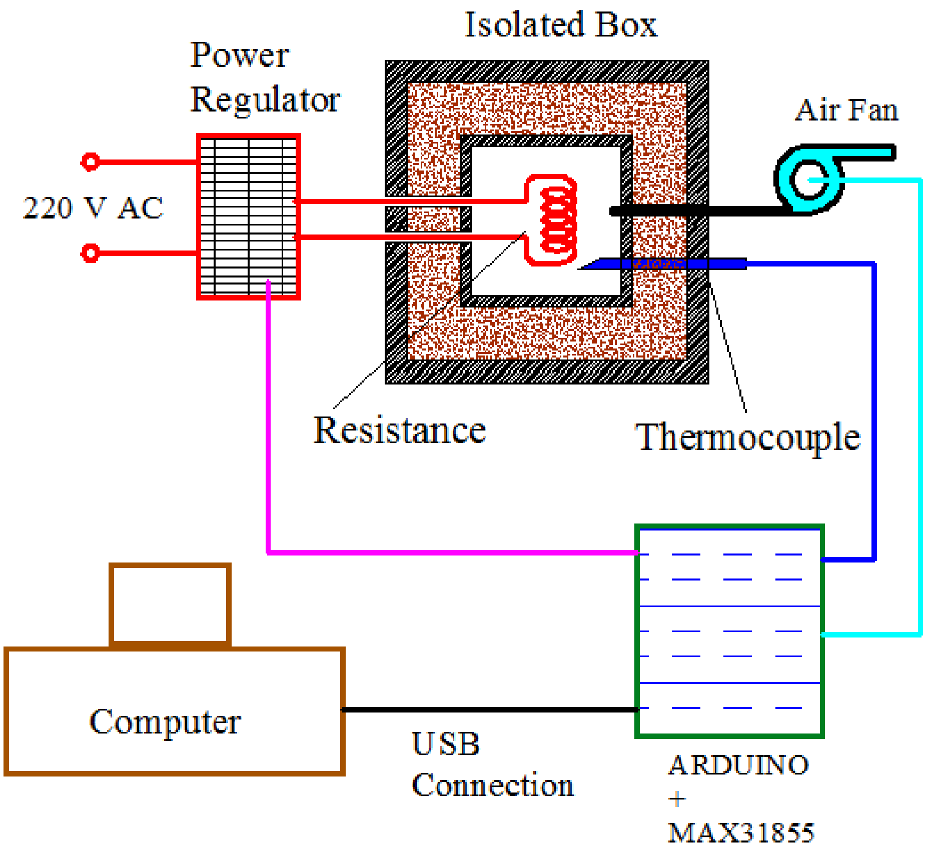

Figure 1. The scheme of temperature controlled heating system

The temperature measuring is done by a thermocouple type-K which produces analog signal at microvolt level. However, Arduino can only read the minimum signal of 4.8 millivolt. Therefore, the signal has to be amplified before the input of Arduino. For this aim, an amplifier called MAX31855 is needed. This device also converts the analog signals to the digital ones. Fig. 3 shows the pictures of Ardunio and MAX31855 amplifier. The measurements are transferred to a computer via a USB connection. With the user defined software, the controller produces the necessary input and transfers the signal through serial ports called SPI (Serial Peripheral Interface) communication from ARDUINO. The input signal is generated as DC Volt to the ELCON regulator and the regulator generates the AC signal to the heater for the control of temperature according to the desired temperature profile. In the mean while, when the rapid temperature drop is needed, an air fan with 100W is used to decrease the temperature by pumping the air at environment temperature into the box. Sometimes the natural cooling cannot produce enough heat transfer for the desired temperature profile. The air fan is controlled by Arduino as on-off.

Figure 2. Power Regulator

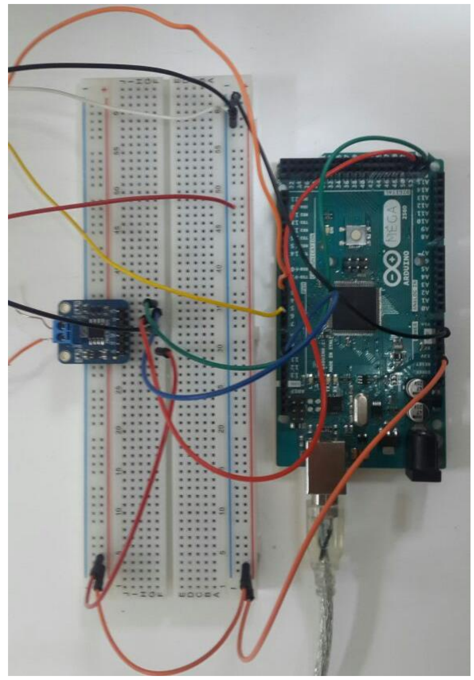

Figure 3. Arduino MEGA 2560 and MAX31855 Amplifier

3. System Modeling

Generally the heating systems are modeled as first order systems with delay time. In Laplace domain, the transfer function between the reference temperature input and the measured temperature at the inside of the box is given as follows.

$$G(s) = T_0 + \frac{K}{1+\tau_2 s} e^{-s\tau_1} \qquad (1)$$

T_0 : Ambient temperature
K : Static gain
τ_1: Apparent time delay
τ_2 : Apparent time constant

The experiment with this system gives the temperature outputs for a step response. For this recorded data set, the parameters can be calculated according to the graphical calculation of process curve method as follows. The details about these calculations can be found in [6].

$$\left.\begin{aligned}\tau_1 &= 66 \text{ seconds} \\ \tau_2 &= 117 \text{ seconds}\end{aligned}\right\} \quad \begin{aligned}\tau_1 + \tau_2 &= t_2 \\ \tau_1 + \frac{\tau_2}{3} &= t_1\end{aligned} \tag{2}$$

K= 420 – 30 = 390 ^{o}C

With this parameter values calculated, the transfer function of the heating system is given in Eq (3). The theoretical and the experimental data have been shown in Fig. 4.

$$G(s) = 30.0 + \frac{390}{1+183s} e^{-105s} \tag{3}$$

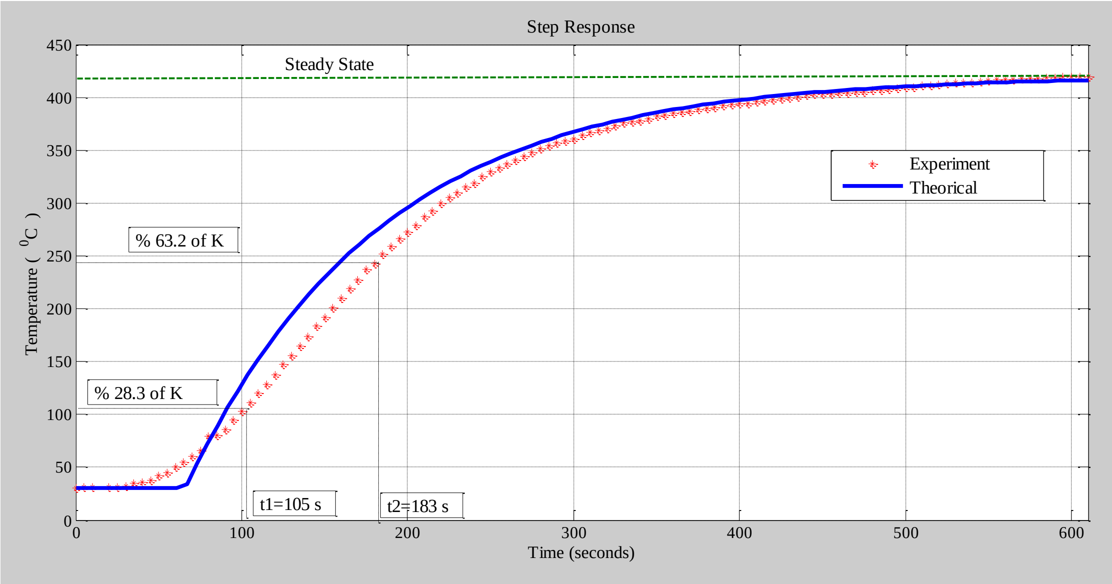

Figure 4. The Theoretical and experimental data

In this research, PID controller is used to compensate the errors. The coefficients of PID (Kp, Ki, Kd) are assigned by trial and error.

4. Experimental Results

The picture of the heating system is shown in Fig. 5 and this system will be assembled to the tension-compression testing machine. The pistons of the testing machine run through the holes of the isolated box and pull and compress the heated material sample at the core of the resistance. The software running the system and connecting the experimental setup to the computer was written in MATLAB. The coefficient of PID controller are assigned by trial and error as $K_p = 80$, $K_I = 0.2$ and $K_D = 40$ with the convenient outputs. Several experiments have been performed to study the performance of the heating system. In one of these experiments, the reference temperature profile consists of some ramp and step inputs. After some successive increasing and decreasing ramp inputs, the temperature of the inside of the box were kept at $200\,^{0}\mathrm{C}$, $350\,^{0}\mathrm{C}$ and $250\,^{0}\mathrm{C}$ respectively as shown in Fig. 6.

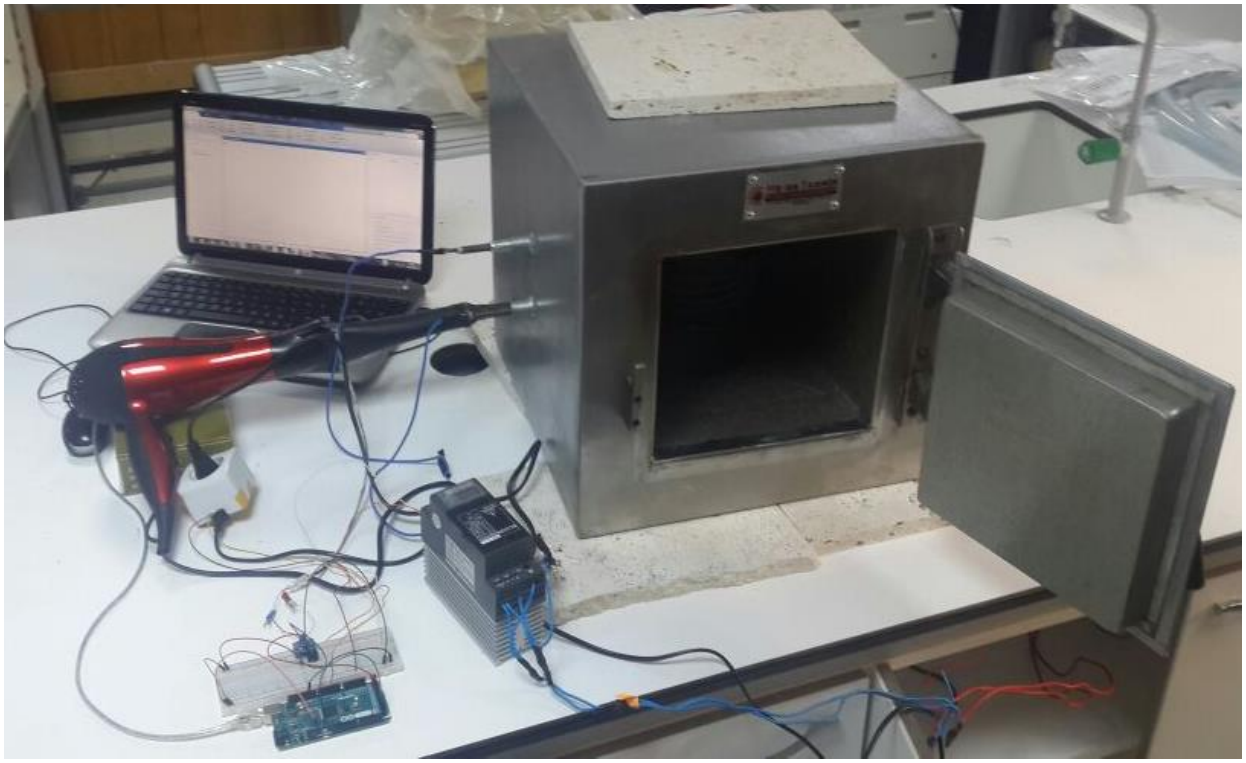

Figure 5. Experimental setup

In this figure, there are some oscillations on the output temperature because the measurement device which is thermocouples is very sensitive to the noises and gives the very low voltage of millivolt level. Any change of the voltage with the noise can be result in very high voltage input for the input of Arduino via the MAX31855 amplifier. Also, there appeared a little time delay. In addition to the reference input and experimental output, the output temperature from the modeling is indicated in Fig. 6. This figure shows the compatibility between the theoretical and experimental results. For this experiment, Fig. 7 shows the input DC voltage generated by Arduino to actuate the heater.

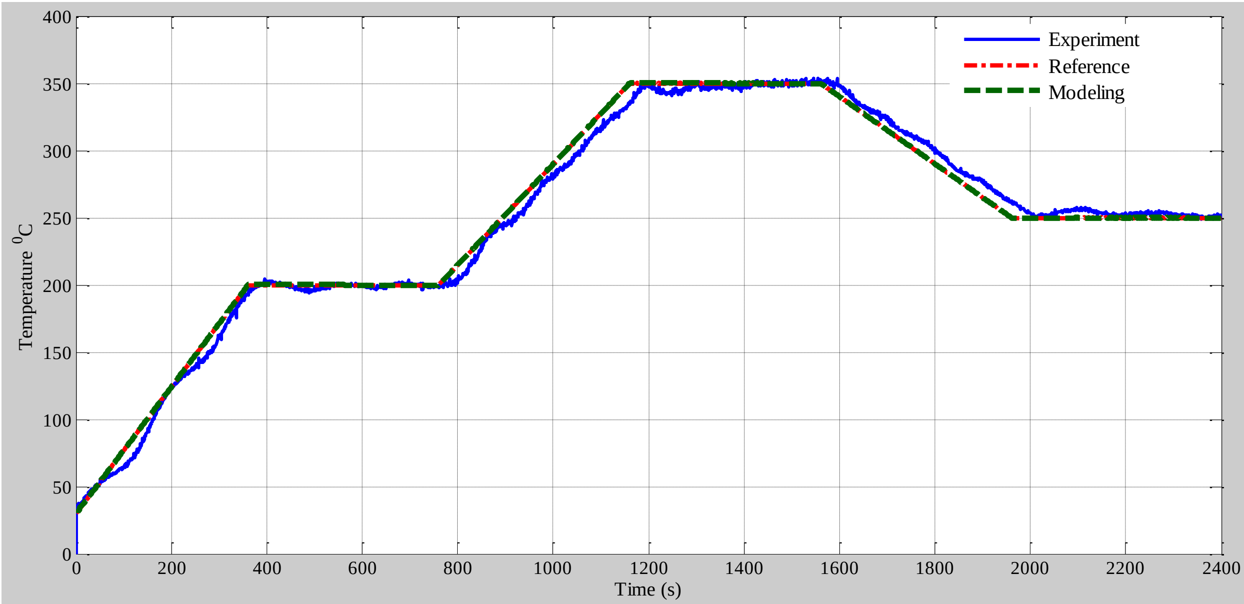

Figure 6. The temperature control

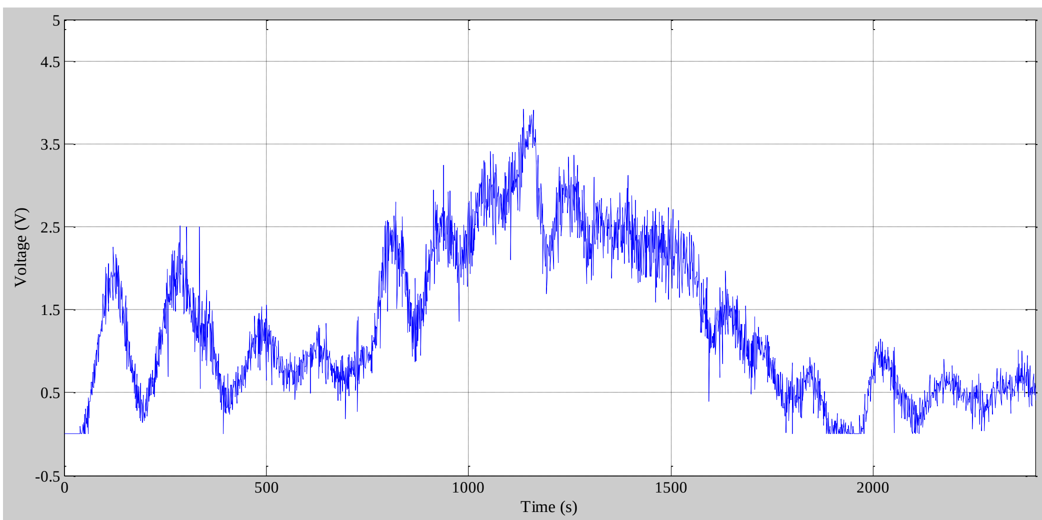

Figure 7. The input DC control voltage for the heater

4. Discussion and Conclusions

The main objective of this work is to create a thermal system to control heating process which consists of some electrical and electronic devices. This system is used for a tension-compression testing machine in the different type of temperature profiles. The experimental setup demonstrates that the performance of the heating process is promising. Also, the experimental outcomes can be fitted to that of the theoretical model pretty well. In this study, the temperature can be measured quickly and successfully and the data can be easily transmitted and processed on the computer via Arduino and MAX31855. However, although the noise on the thermocouple did not create a significant problem, it should be taken into account for the data processing because thermocouples are very sensitive to noise and the amplifier can strengthen this noise. Then, the internal metal walls of the isolated box store the heat energy and thus it behaves as a disturbance. In addition to these, the coefficients of PID controller should be adjusted adaptively for fine tuning of the temperature. Nevertheless, conceivably accurate outcomes were obtained in spite of these drawbacks.

The future work is focused on to design cooling system because it is very important in the industrial process by using new application of science and technology such as liquid nitrogen to cooling for very low temperature (cryogenic cooling system).

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