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ORIGINAL RESEARCH PAPER

Control of air flow temperature and pressure in the pipelines with PID

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ABSTRACT

Today, the use of proportional-integral-derivative (PID) control units continues in many control applications due to their simple structure. In areas such as pressure, temperature, flow control, PID control element is used and many new methods are applied in adjusting control parameters. In this study, the LTR 701 Controlled Airflow and Temperature Experimental System was used to study the temperature and pressure control at different flow rates in the pipelines. In this control system, temperature was controlled with PID control element, pressure was controlled with PI control element, and reaction of control parameters at different temperatures and pressures were investigated. Also, temperature was controlled as cascade with PI element in elementary controller and P element in secondary controller. The manual adjustment method has been applied to adjust the control parameters. In addition, the experimental system is modelled in MATLAB-SIMULINK. On this model, simulation results showed that it is matching the experimental results.

KEYWORDS

PID control, temperature control, pressure control, control simulation

1. INTRODUCTION

In the control training, it is important to apply the theoretical knowledge and to compare the theoretical knowledge with the applications [1, 2]. The proportional-integral-derivative (PID) control element, which has an important place in automatic control systems, is widely used in the industry and constitutes an important part of industrial control systems. Therefore, any improvement in PID design and application methods will have important effects on industrial control systems [3–5].

There are many academic studies using PID control elements. Hok et al. controlled a time delayed non-linear pressure control system with a numerical PI control element. The model of the control system is extracted as a first-order transfer function with time delay, and based on this model, the control element is optimized according to the open-cycle frequency response by the method of Ziegler–Nichols [6]. Soyguder et al. performed modelling, numerical simulation and control of a variable flow HVAC (heating ventilation air conditioning) system which has two different areas in Matlab-SIMULINK. The sub-models of the system are derived from the heat transfer equations of heat loss due to convection, conduction, cooling unit and fan between the two regions. The system was controlled by self-tuning PID type fuzzy adaptive control element, and successful results were obtained. These results are also compared with the results obtained with fuzzy PD and conventional PID controller [7].

Ünal used genetic algorithm and ant-colony algorithm to optimize the coefficients of the PID control element used in the control of a pressure process control unit. He obtained the dynamic model of the system to be controlled by using artificial neural network and optimized the PID control element on this model by genetic algorithm, ant colony algorithm and Ziegler–Nichols methods [8]. Kayacan used the PID control element which was

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obtained with the fuzzy control theory and the gray system theory on a non-linear liquid level control scheme [9].

Bolat designed a PIC-based card to provide real-time control of a furnace via Matlab-SIMULINK simulation software and controlled furnace temperature by transmitting of control information generated in Matlab-SIMULINK environment. In addition, he has simulated the furnace with PI parameters determined by the Ziegler–Nichols Step Response Field Method and the Fuzzy Gain Control PI Controller [10]. Akgül modelled a greenhouse with a fuzzy logic method, in a natural aeration system, in order to provide temperature and relative humidity control and decided how much greenhouse windows should be opened by this method [11].

As can be seen, there are some studies about the applications of PID control elements in ventilation systems. In this study, various control experiments were conducted with control elements such as P, PI and PID to check the temperature and pressure of a pipe with passing air in it. For these experiments, the LTR 701 Controlled Airflow and Temperature System was used, and the performances of the control elements under different conditions were compared. On the other hand, system is modelled in Matlab-SIMULINK with using the transfer functions of this control system, and the obtained simulation results are compared with each other and the actual results of the control system.

2. EXPERIMENTAL SYSTEM AND ITS MATHEMATICAL MODEL

The LTR 701 Controlled Airflow and Temperature System is an experimental setup that enables the specification of the control systems and the performance of the various control elements. These controls are provided by changing the temperature, flow rate and pressure with five analogue output variables (flow rate, 2 temperature, pressure and throttle position) and two input variables (ventilator speed and heater output). The system consists of a fan, heater, flow metre, measuring tube, air inlet valve, valve sensor, two temperature sensors, pressure sensor, analogue data card, pc and thermocouple. Manually adjustable air inlet angle can be applied as a disruptive effect to the system. Figure 1 shows the experimental apparatus with PC.

2.1. Control cycle of temperature

In this cycle, the air flow is uncontrolled and the controller only controls the temperature. Control of this temperature cycle in the system can be achieved with the PID control element. The block diagram of this cycle can be seen in Fig. 2.

Transfer function of this cycle is as follows;

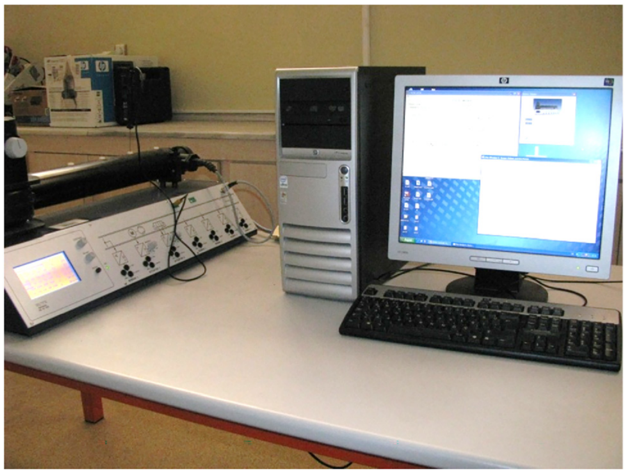

Fig. 1. Air flow and temperature control test setup

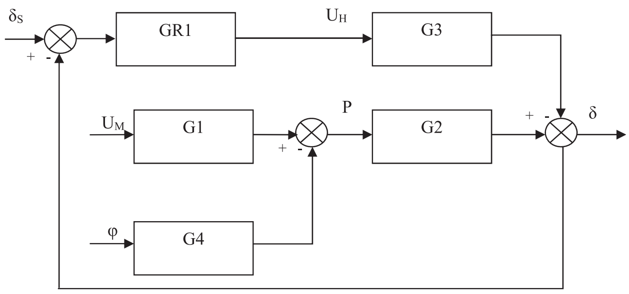

Fig. 2. Block diagram of temperature control cycle

$$\delta = (\delta S - \delta).GR1.G3 + (UM.G1 + \varphi.G4).G2 \tag{1}$$

$$\delta + \delta.GR1.G3 = \delta S.GR1.G34 + UM.G1.G2 + \varphi.G4.G2 \tag{2}$$

$$\frac{\delta}{\delta s} = \frac{GR1.G3 + G2.(Um.G1 + \varphi.G4)}{1 + GR1.G3 + G2.(Um.G1 + \varphi.G4)} \tag{3}$$

2.2. Pressure control cycle

In this cycle, the temperature is uncontrolled and the controller only performs the pressure control. In the system, the control of this pressure cycle can be achieved with the PI control element. The block diagram of this cycle can be seen in Fig. 3.

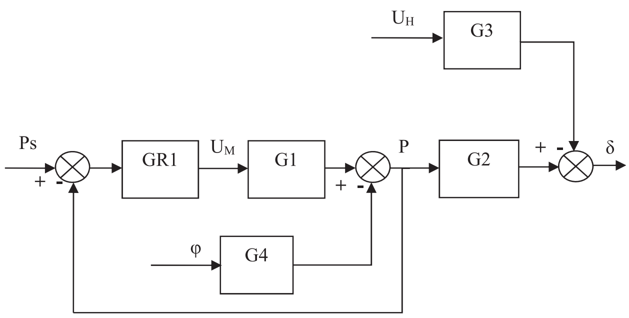

Fig. 3. Block diagram of the pressure control cycle

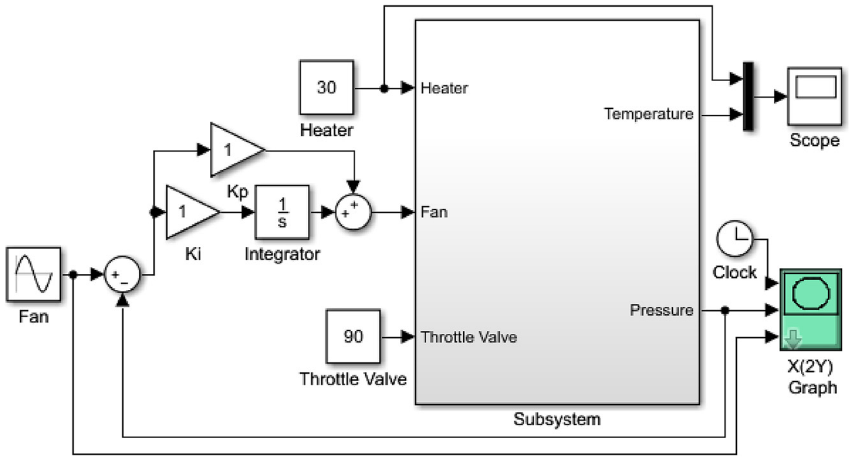

Fig. 4. Model of PI pressure control in SIMULINK

Transfer function of this cycle is as follows;

$$P = (PS - P).(GR1.G1 + \varphi.G4) \tag{4}$$

$$P = PS.GR1.G1 + \varphi.G4.PS - P.GR1.G1 - P.\varphi.G4 \tag{5}$$

$$\frac{P}{Ps} = \frac{GR1.G1 + \varphi.G4}{1 + GR1.G1 + \varphi.G4} \tag{6}$$

The transfer functions that showed in the system model are as follows;

G1(s) = The transfer function of the fan effect to pressure
G2(s) = The transfer function of the pressure effect to temperature
G32(s) = The transfer function of the heating effect on sensor 2
G33(s) = The transfer function of the heating effect on sensor 3
G4(s) = The transfer function of the air inlet angle effect to pressure

The values of these transfer functions are as follows;

$$G1(s) = \frac{\Delta p}{\Delta Um} = e^{-0,24.s}.\frac{0,425}{2,4.s + 1} \tag{7}$$

$$G2(s) = \frac{\Delta \delta}{\Delta p} = e^{-0,7.s}.\frac{0,368}{8,35.s + 1} \tag{8}$$

$$G32(s) = \frac{\Delta \delta}{\Delta UH} = e^{-0,3.s}.\frac{0,543}{3,3.s + 1} \tag{9}$$

$$G4(s) = \frac{\Delta p}{\Delta \varphi} = \frac{0,03}{2,1.s + 1} \tag{10}$$

2.3. Designing of the experimental system in MATLAB-SIMULINK

MATLAB is a software which can be used in many areas such as control systems, power systems, filter design, genetic algorithm, graphics, database, finance, fuzzy control, neural networks, optimization, image processing and statistics. Many toolboxes for these workspaces are available in the program SIMULINK, a very important and visual toolbox in MATLAB. It is a virtual lab for modelling and simulating of dynamic systems. Pressure and temperature control experiments which performed in the LTR 701 were designed and controlled in MATLAB-SIMULINK.

2.3.1. Designing of PI pressure control in SIMULINK. In designing this control cycle, the system model is built on a subsystem. In the system, pressure control is provided by PI control element. The model of PI pressure control in SIMULINK can be seen in Fig. 4.

2.3.2. Designing of PID temperature control in SIMULINK. Temperature control is performed in this control cycle and PID control element is used as the control element. The model of the PID temperature control in SIMULINK can be seen in Fig. 5.

2.3.3. Cascade control of temperature. LTR 701 Controlled Airflow and Temperature System allows to cascade control of temperature. In the system, the main controller of this loop is the PI control element and the secondary controller is the P controller. The block diagram and SIMULINK model of the system are shown in Fig. 6.

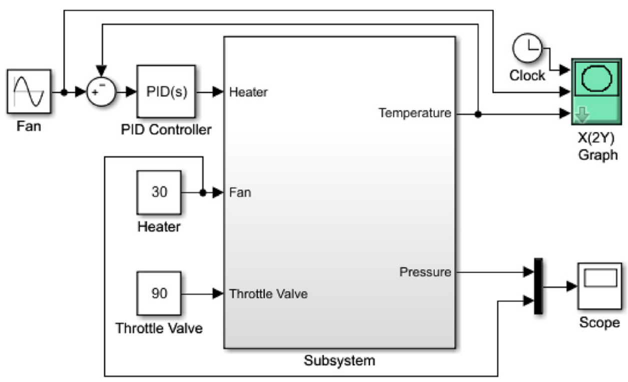

Fig. 5. Model of PID temperature control in SIMULINK

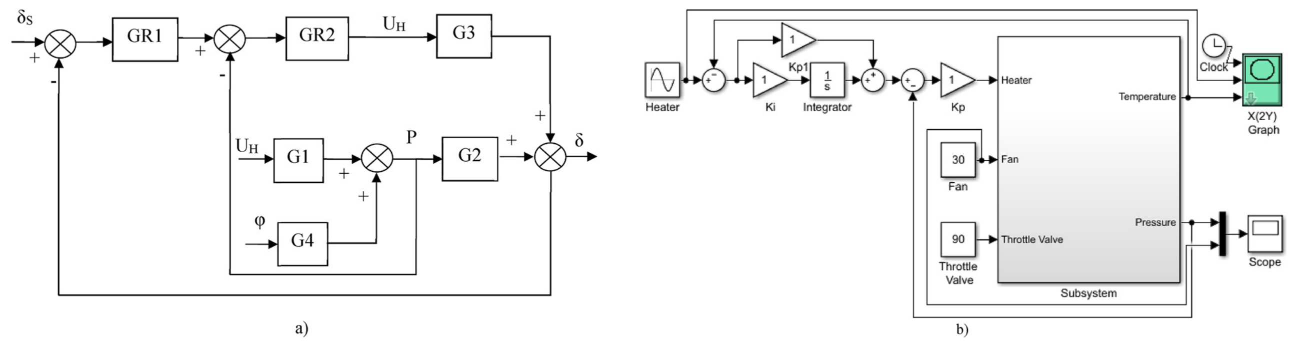

Fig. 6. a) Block diagram of cascade temperature control, b) SIMULINK model of cascade temperature control

3. FINDINGS AND DISCUSSION

3.1. Comparison of simulation and experimental results in temperature control

In the model of the airflow and temperature system which was created in MATLAB-SIMULINK, simulations of the temperature control experiments were made and compared with the actual results. Temperature control with P, PI and PID was performed using Kp, Ki, and Kd parameters that were manually determined as in the test system. The parameters used in SIMULINK are;

Kp = 3.371
Ki = 2.748
Kd = 1.799

The parameters used in the experimental setup are;

Kp = 60.000
Ki = 45.880
Kd = 25.940

When the results are examined, in the experimental P control (Fig. 7(a)), the system catches the desired response in a very short time, but oscillations are seen at the peak points. But the control results are not obtained in the

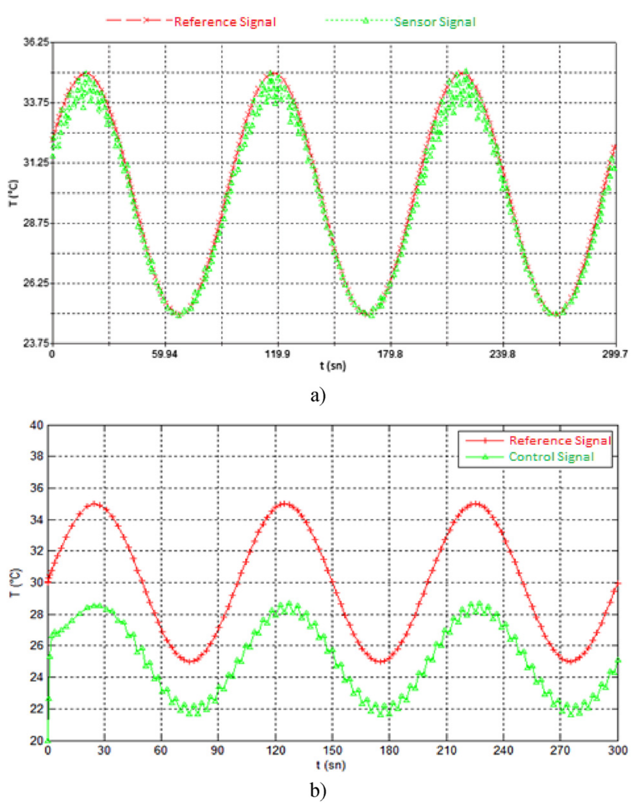

Fig. 7. In the temperature control with P control element; a) The changing in response of the airflow and temperature system to the sinusoidal input signal, b) The changing in response of the SIMULINK model to the sinusoidal input signal

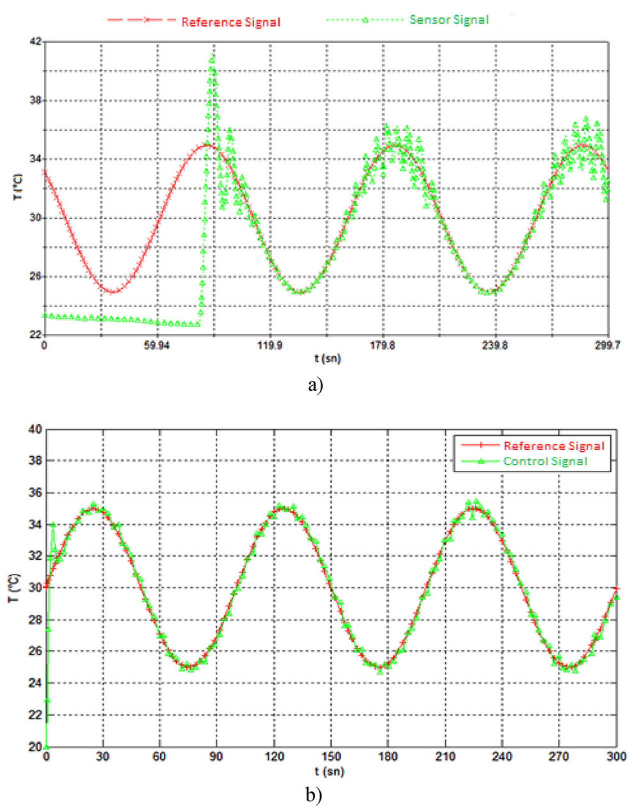

Fig. 8. In the temperature control with PI control element; a) The changing in response of the airflow and temperature system to the sinusoidal input signal, b) The changing in response of the SIMULINK model to the sinusoidal input signal

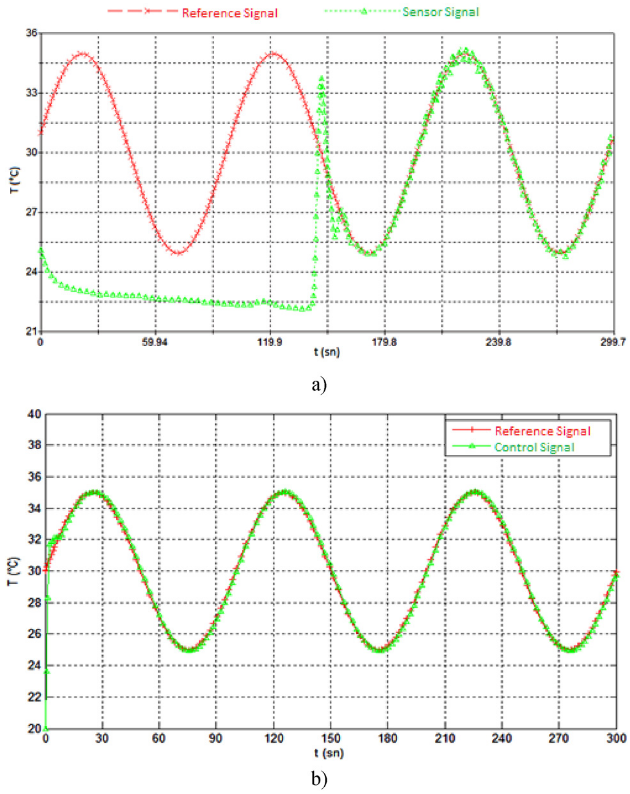

Fig. 9. In the temperature control with PID control element; a) The changing in response of the airflow and temperature system to the sinusoidal input signal, b) The changing in response of the SIMULINK model to the sinusoidal input signal

simulation results (Fig. 7(b)). In the PI control, it is seen that integral activation increases the settling time, oscillations and maximum overshoot of the response in the experimental data (Fig. 8(a)). In simulations (Fig. 8(b)), it provides controlling of temperature and reduces the settling time. In PID control, the differential effect decreases the maximum overshoot and oscillation, but increases the settling time of the test results (Fig. 9(a)). In simulations (Fig. 9(b)), it also reduces the maximum overshoot and oscillations but does not increase the settling time.

3.2. Comparison of simulation and experimental results in cascade temperature control

In temperature control with constant pressure, temperature is controlled with variable of the external control loop, while the pressure is controlled with variable of the gradual control loop. In this position, the heater is activated by the secondary control element and the fan is fixedly set. In the system, the main controller of this loop is the PI control element and the secondary controller is the P controller. The parameters of the primary control element are;

Kp = 30.900
Ki = 15.660

The parameter of the secondary control element is;

K = 50.750

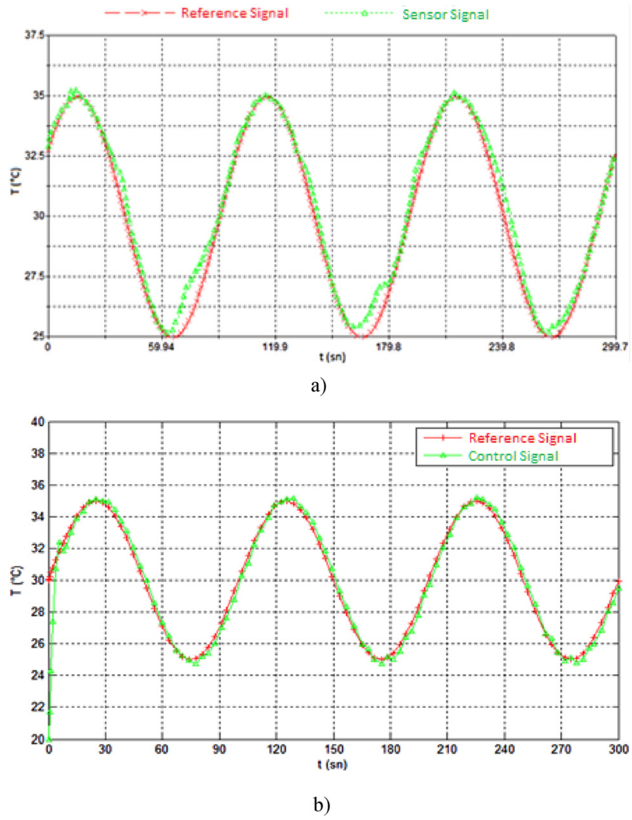

Fig. 10. In the cascade temperature control; a) The changing in response of the airflow and temperature system to the sinusoidal input signal, b) The changing in response of the SIMULINK model to the sinusoidal input signal

The parameters of the primary and secondary control elements used in SIMULINK are;

Kp = 2.839
Ki = 2.083
K = 0.700

When the results are examined, it is seen that the settling time in cascade control is very short compared to PID temperature control. It is seen that the cascade control follows the lower temperature values with difficulty (Fig. 10(a)). This is due to the fact that the fan operates at a constant value in cascade temperature control. In the SIMULINK model, the settling time is very short and the control signal follows the sinusoidal signal with very little delay (Fig. 10(b)).

3.3. Comparison of simulation and experimental results in pressure control

In the test system, P and PI pressure controls were made using Kp and Ki parameters manually determined. The parameters used are;

Kp = 60.500
Ki = 45.600

The parameters used in SIMULINK are;

Kp = 2.707
Ki = 2.500

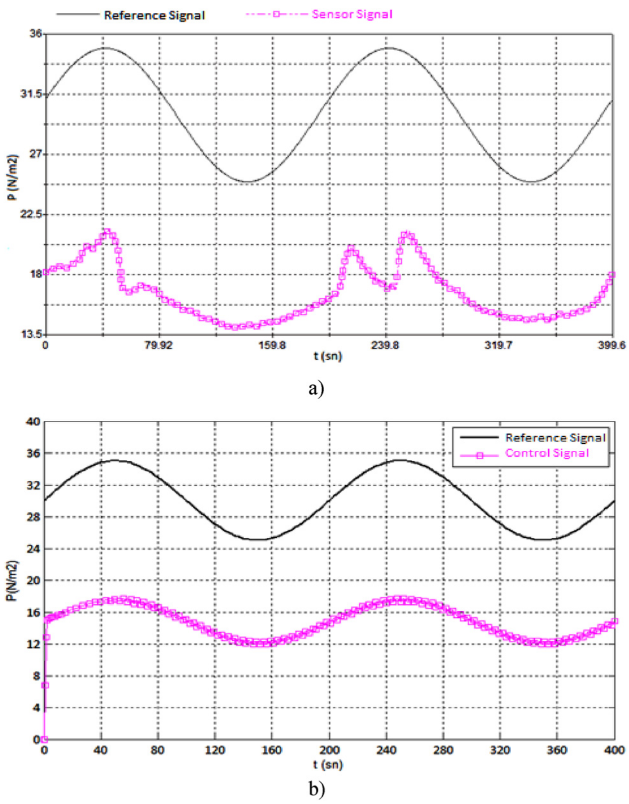

Fig. 11. In the pressure control with P control element; a) The changing in response of the airflow and temperature system to the sinusoidal input signal, b) The changing in response of the SIMULINK model to the sinusoidal input signal

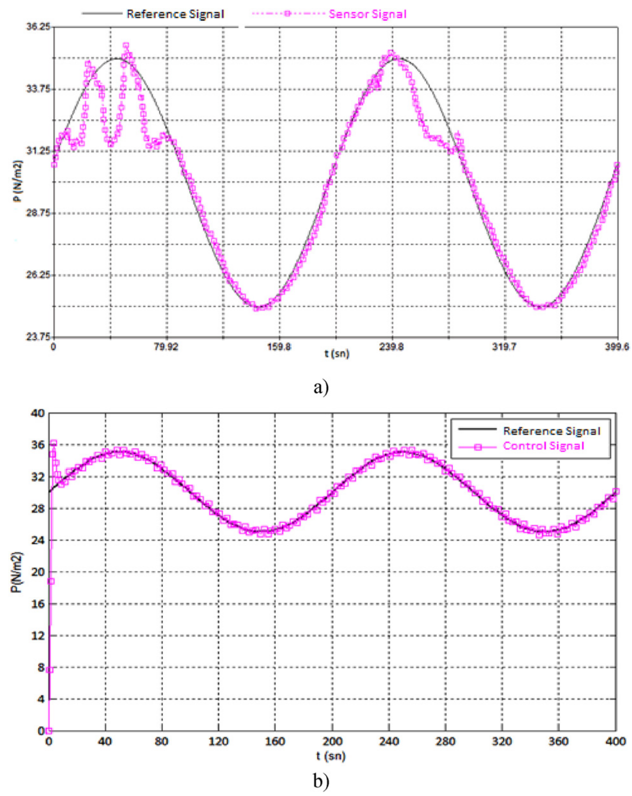

Fig. 12. In the pressure control with PI control element; a) The changing in response of the airflow and temperature system to the sinusoidal input signal, b) The changing in response of the SIMULINK model to the sinusoidal input signal

When the results are compared, it can be seen that the system does not catch the desired value and sudden drops occur at the peak points in the experimental P pressure control (Fig. 11(a)). Also, simulation results (Fig. 11(b)) almost coincide with experimental results. In PI control, the system (Fig. 12(a)) follows the desired value. However, it is observed that there are declines at the peak and the time of settlement is very low. In simulation results (Fig. 12(b)), it is seen that the maximum overrun and settling time are higher than the experimental results, but the oscillations are less.

4. RESULTS

In this study, the air flow rate and temperature are controlled by standard feedback P, PI, PD and PID controllers in the LTR 701 Airflow and Temperature System, which is a prototype of a heating and cooling system. In addition, with the help of the theoretical model of the system, the pressure effect and the temperature change were controlled with the same control organs in Matlab-SIMULINK as a simulation. As a result of these studies, the following results were obtained:

- Based on the experimental P, PI, and PID temperature control results, it was observed that the settlement time and maximum overrun were low, but the oscillations were high in the P control. The integral effect increases the maximum overshoot and settlement time, while the derivative effect reduces the maximum overrun. PID control by combining the appropriate parameters gives good results.
- According to the simulation results, P control follows the sinusoidal signal below the desired value. In the PI control, the sinusoidal signal is caught and the maximum exceeding value is decreased by adding the derivative effect.
- The settling time is very short in cascade temperature control compared to PID temperature control. It is seen that the cascade control follows the lower temperature values with difficulty. This is due to the fact that the fan operates at a constant value in cascade temperature control. In the SIMULINK model, the settling time is very short and the control signal follows the sinusoidal signal with very little delay.
- Experimental P and PI pressure control results show that the using of the proportional effect alone results in failure of the pressure control and PI control with the integral effect provides the desired control result.

According to the simulation results, P control follows the sinusoidal signal at the desired value as in the temperature control. In PI control, sinusoidal signal is captured and pressure control is provided.

REFERENCES

[1] M. S. Qureshi, P. Swarnkar, and S. Gupta, "A supervisory on-line tuned fuzzy logic based sliding mode control for robotics: An application to surgical robots," *Robot. Auton. Syst.*, vol. 109, pp. 68–85, 2018.
[2] J. Zhang, "Design of a new PID controller using predictive functional control optimization for chamber pressure in a coke furnace," *ISA Trans.*, vol. 67, pp. 208–214, 2017.
[3] S. S. Yurdakul and İ. Eker, *Self-tuning PID Control with Experimental Applications, EMO 5.* Automation Symposium, 2009.
[4] Ş. Yıldırım and S. Savaş, "Trajectory control of a mobile robot using neural network for frail blind persons," *Int. Rev. Appl. Sci. Eng.*, vol. 4, no. 1, pp. 27–34, 2013.
[5] S. M. Attaran, R. Yusof, and H. Selamat, "A novel optimization algorithm based on epsilon constraint-RBF neural network for tuning PID controller in decoupled HVAC system," *Appl. Therm. Eng.*, vol. 99, 613–624, 2016.
[6] H. S. Mok, G. T. Kim, M. H. Park, and H. W. Rhew, "PI controller gains tuning of the pressure control system by open-loop frequency response," *IEEE*, vol. 88, pp. 557–561, 1988.
[7] S. Soyguder, M. Karaköse, and H. Alli, "Design and simulation of self-tuning PID-type fuzzy adaptive control for an expert HVAC system," *Expert Syst. Appl.*, vol. 96, pp. 4566–4573, 2009.
[8] M. Ünal, H. Erdal, and V. Topuz, "Trajectory tracking performance comparison between genetic algorithm and ant colony optimization for PID controller tuning on pressure process," *Comput. Appl. Eng. Educ.*, vol. 20, no. 3, pp. 518–528, 2012.
[9] E. Kayacan, *Grey Prediction Based Control Based Control Of A Non-linear Liquid Level System Using PID Type Fuzzy Controller*, Master Thesis, Boğaziçi University, İstanbul, 2006.
[10] Y. Bolat, *Matlab-SIMULINK + PIC Based Fuzzy Logic Controller Design and Implementation of Real Time Temperature Control*, Master Thesis, Marmara University, 2006.
[11] H.N. Akgül, İ. Kavdır, and M.A. Dayıoğlu, "Trajectory tracking performance comparison between genetic algorithm and ant colony optimization for PID controller tuning on pressure process," *Tar. Mak. Bil. Der.*, vol. 2, no. 1, pp. 57–63, 2006.