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Improvement of Dyeing and Weaving Hot Water Temperature Control System Response Using a PID Controller

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Abstract— *This paper has presented improvement of dyeing and weaving hot water temperature control system response using proportional integral and derivative (PID) controller. It is required to improve the response performance of a temperature control system for dyeing and weaving process whose response is slow and overdamped. In order to do this, the dynamic model of a hot water temperature control system was obtained. A robust proportional integral and derivative (PID) controller was designed using the PID tuner of the Matlab software. The designed PID controller was integrated with the dynamic model of the temperature control system. Simulations were performed in Matlab environment. The results obtained showed that the PID controller was able to improve the transient response performance of the system in terms of rise time of 0.415 seconds, settling time of 2.49 seconds, and overshoot of 8.78 %. This indicates a fast response system.*

Keywords— *Controller, Matlab, PID, Response performance, Temperature*.

I. INTRODUCTION

In an industrial process where it is required to know the actual temperature of the system and regulates it automatically, an essential part of the larger unit which depends on feedback is a temperature controller (Jack, 2002). A temperature controller is needed when it is required to keep the temperature of a process stable. A process may be required to be heated, cooled or both and to maintain a setpoint or desired temperature irrespective of the changes taking place in the environment around it (Parlow and West, 2017). Any device that is used to keep the temperature of a process or system at a desired value is a temperature controller.

One of the elements of a closed loop temperature control system is a sensor. The dynamic response of such sensor must be given an important consideration when designing the measurement system (Anonymous, 2006). Nowadays, modern temperature controllers use thermocouples and resistance temperature detectors (RTDs) as temperature sensors. They provide the necessary feedback mechanism for the temperature control system. There are many industrial processes or operations which use temperature controller. The temperature sensor measures the response temperature of the control system and feed it to a comparator. The comparator compares the measurement from the sensor with the setpoint signal and output error signal to the temperature controller to make adjustment or regulate the output or response temperature if necessary.

Some applications of temperature controller in industrial or manufacturing process are plastic extrusion and injection molding machines, thermos-forming machines, packaging machines, food storage, and blood banks (Parlow and west, 2017). Another area of temperature control is in the application of hot water for domestic purposes and industrial use. One of such area of applications in industry were hot water is very much consumed is the dyeing and weaving industry (Anonymous, 2013).

There are several works in literature on temperature control system with different approach and control techniques used to achieve research objective. Jean et al. (2015) designed a temperature control system using conventional and intelligent fuzzy logic controller for industrial heat treating furnace. Wei and Xuchu (2012) presented a temperature control system based on the fuzzy self-tuning proportional integral and derivative (PID). A remote temperature control is proposed in (Ikhlef, 2015). The internet work was used to control the physical system in real time. The parameters of the PID were calculated using Zigler-Nichols tuning. Modeling and simulation of temperature control system of coating plant air conditioner is presented in (Dong, 2017). In (Anonymous, 2006), transient response of a thermocouple to a step temperature change for a first-order system is presented.

In this paper, a robust proportional integral and derivative (PID) controller is designed to improve the response performance of a dyeing and weaving hot water temperature control system.

II. PROBLEM FORMULAION

A temperature control system is required to produce a steady stream flow of hot water at a controlled temperature with improved fast response performance for a dyeing and weaving process. The temperature of the outflowing water is measured by means of a feedback temperature sensor (thermocouple) which produces an output electrical voltage signal proportional to the temperature of the flowing water. The output temperature is subtracted from a referenced temperature to generate the error signal, E (where $E = \theta_i - \theta_o$), which is fed into the controller and then giving rise to the manipulated variable that acts on the system.

In this paper, the following assumptions are made to reduce the complexity of the system (Nagrath and Gopal, 2005) as shown in Fig. 1.

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1. The inflow and outflow rate of water for the tank are the same so that the water level is kept constant during the operation
2. The water in the tank is well-stirred so that its state can be represented by temperature θ_o of the outflowing liquid.
3. Heat loss through the walls of the tank is negligible.
4. The tank walls have negligible heat storage capacity
5. The operation of the control unit is linear.

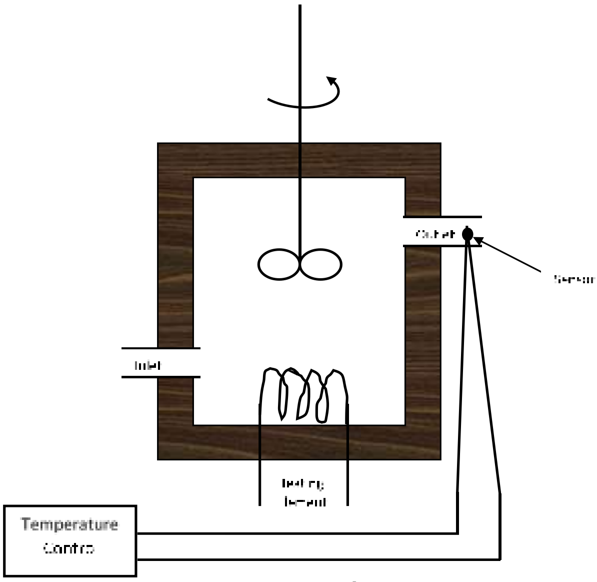

Fig. 1. Hot water tank system.

III. METHODOLOGY

A. Dynamic Modelling

The modelling of the system in Fig. 1 adopts the approach used in (Saeed, 2012).

Let θ_i = inflowing water temperature in (^{o}C)

θ_o = outflowing water temperature in (^{o}C)

θ = temperature of the surrounding walls of the tank in (^{o}C)

Q = rate of heat flow from heating elements (J/s)

Q_w = rate of heat flow to the water (J/s)

Q_t = rate of heat flow through the tank wall

C = thermal capacitance (J/ ^{o}C)

R = thermal resistance

Rate of heat flow for the water in the tank is:

$$Q_w = C\frac{d\theta_o}{dt} \tag{1}$$

Rate of heat flow from water to the surrounding through insulation

$$Q_t = \frac{\theta_o - \theta}{R} \tag{2}$$

$$Q = Q_w + Q_t \tag{3}$$

$$Q = C\frac{d\theta_o}{dt} + \frac{\theta_o - \theta}{R} \tag{4}$$

Assuming $\theta = 0$, as in assumptions 3 and 4, (4) is simplified as given in (5):

$$Q = C\frac{d\theta_o}{dt} + \frac{\theta_o}{R} \tag{5}$$

Simplifying and taking the Laplace transform of (5) gives:

$$QR(s) = sCR\theta_o(s) + \theta_o(s) \tag{6}$$

$$\frac{\theta_o(s)}{Q(s)} = \frac{R}{sCR+1} \tag{7}$$

Substituting $\tau = CR$ into (7) gives:

$$G_p = \frac{R}{\tau s+1} \tag{8}$$

where τ is time constant in second.

Using the transfer function equation in (Richard and Robert, 2011) it can be seen that $R = 0.8$ and $\tau = 3$ as such (8) is expressed as:

$$G_p = \frac{0.8}{3s+1} \tag{9}$$

Equation (9) gives the process considered in this paper.

B. Design Performance Criteria

The objective of this paper is to design a controller that will improve the response performance of a temperature control system. The system response must be fast and not overdamped. In order to achieve this objective, the following performance criteria must be met:

Rise time of 0.6 second or less

Settling time (with a 2% criterion) of 3 seconds or less

Overshoot of 10 % or less

The system should not be slow and over damped

C. System Configuration and Controller Design

The configuration of the system for the temperature control system considered in this paper is shown in Fig. 2. The controller and the process are all on the forward path. The temperature sensor has a unit feedback gain.

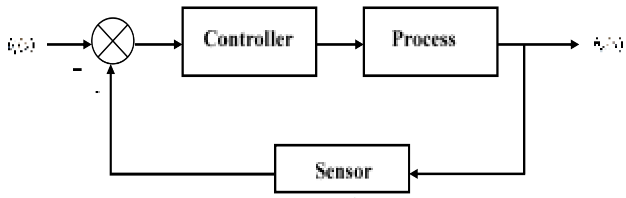

Fig. 2. System configuration.

A proportional integral and derivative (PID) controller is designed in this paper to improve the transient response performance of the temperature control system. The tuned PID controller parameters are presented table I and the controller is presented in (10) below.

TABLE I. Designed PID controller parameters.

Controller Parameters	Tuned
k_p	15.187
k_i	17.0035
k_d	0.31331

$$C(s) = K_p + k_i \frac{1}{s} + k_d s \tag{10}$$

$$C(s) = 15.187 + \frac{17.0035}{s} + 0.31331s \tag{11}$$

$$G(s) = \frac{0.2506s^2 + 12.15s + 13.6}{3.251s^2 + 13.15s + 13.6} \tag{13}$$

Equation (13) is the closed loop transfer function of the system with the PID controller added to the forward path.

IV. Simulation Results and Discussion

A. Simulation Results

The simulation results obtained considering when the controller is not in the loop and when it is in the loop are presented in Fig. 3 and 4. The system performance is presented in table II.

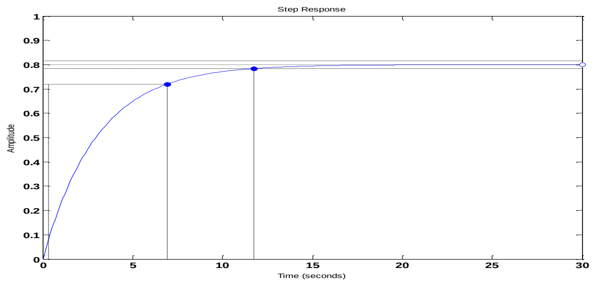

Fig. 3. Step response (without PID controller).

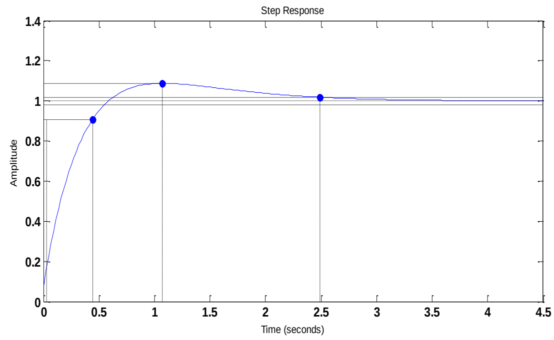

Fig. 4. Step response (with controller).

TABLE II. System performance to a unit step response.

System	Rise time	Settling time	Overshoot	Remark
Without controller	2.17 s	3.86 s	0 %	Slow
With controller (PID)	0.415 s	2.49 s	8.78 %	Fast

B. Discussion

Fig. 3 shows the step response performance of the hot water system without the controller in the loop. It can be seen that the system is slow and overdamped. So the system performance needs to be improved. A robust proportional integral and derivative (PID) controller is added to the loop as shown in Fig. 4. It can be seen that with PID controller in the loop, the step response performance of the system is improved.

Table II shows the characteristics performance of the system obtained from the simulation performed in terms of the rise time, settling time and overshoot. It can be seen from table II that the system performance appreciably improved with the designed robust PID controller added to the loop and thereby achieving the designed performance criteria.

V. Conclusion

This paper has presented transient response performance improvement of a dyeing and weaving hot water temperature control system using a proportional integral and derivative (PID) controller. A model of a typical temperature system was obtained for water heating system. It is required that the response performance of the system be improved. In order to achieve this, a robust PID controller is designed and integrated into the control loop. Simulation results obtained showed that the designed robust PID control was able to improve the response performance of the temperature control system considered in this paper. The designed controller can be applied in temperature control system were automatic control of hot liquid such as water from tank or reservoir is required for domestic or industrial use with fast response performance.

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