International Journal of Electrical and Computer Engineering (IJECE)
Vol. 5, No. 3, June 2015, pp. 436~442
ISSN: 2088-8708

PID Controller Design for Two Tanks Liquid Level Control System using Matlab

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Article Info

Article history:

Received Oct 30, 2014
Revised Apr 22, 2015
Accepted May 8, 2015

Keyword:

Coupled tank system
PID controller
PID tuning method
Water level control

ABSTRACT

The industrial application of Coupled Tank System (CTS) is widely used especially in chemical process industries. The control of liquid level in tanks and flow between tanks is a problem in the process technologies. The process technologies require liquids to be pumped, stored in tanks, and then pumped to another tank systematically. This paper presents development of Proportional-Integral-Derivative (PID) controller for controlling the desired liquid level of the CTS. Various conventional techniques of PID tuning method will be tested in order to obtain the PID controller parameters. Simulation is conducted within MATLAB environment to verify the performances of the system in terms of Rise Time (Ts), Settling Time (Ts), Steady State Error (SSE) and Overshoot (OS). The trial and error method of tunning will be implemented and all the performance results will be analyzed using MATLAB. It has been demonstrated that performances of CTS can be improved with appropriate technique of PID tuning methods.

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1. INTRODUCTION

Proportional Integral Derivative (PID) controllers are widely used in industrial practice since last six decade. The invention of PID control is in 1910 (largely owing to Elmer Sperry's ship autopilot) and the straightforward Ziegler-Nichols (Z-N) tuning rule in 1942 [1]. Today, PID is used in more than 90% of practical control systems, ranging from consumer electronics such as cameras to industrial processes such as chemical processes. The PID controller helps to get our output (velocity, temperature, position) where we want it, in a short time, with minimal overshoot, and with little error [2]. It also the most adopted controllers in the industry due to the good cost and given benefits to the industry [3]. Many nonlinear processes can be controlled using the well known and industrially proven PID controller [4]. A considerable direct performance increase (financial gain) is demanded when replacing a conventional control system with an advanced one [4]. The maintenance costs of an inadequate conventional control solution may be less obvious. The tricky part of controller design is to figure out just how much of a corrective effort the controller should apply to the process in each case. Some situation requires tighter control of the process variable than On-Off control can provide.

Proportional control provides better control because its output operate linearly anywhere between fully ON and fully OFF [5]. As its name implies, its output changes proportionally to the input error signal. Proportional controller simply multiplies the error by a constant to compute its next output.

In 1930s the control engineers discovered that the error could be eliminated altogether by automatically resetting the set point to an artificially high value [3]-[6].

The PID controllers function is to maintain the output at a level that there is no difference (error) between the process variable and the set point in as fast response as possible.

The objective of the controller in the level control is to maintain a level set point at a given value and be able to accept new set point values dynamically.

This paper considers the designing of PID Controller to control coupled tank system using MATLAB software. This software is used to create the simulink model for PID Controller and performance for each parameter for PID Controller has been simulated. The performances of PID Controller are evaluated in terms of overshoot, rise time and steady state error. Then, the gain for each parameter will also be tuned in this software and the validity for each parameter will be compared using the reference value (set point).

2. MODELING OF THE COUPLED TANK SYSTEM

Consider the process consisting of two interacting liquid tanks in the Figure 1. The volumetric flow into tank1 is q_{in}(cm^3/min), the volumetric flow rate from tank1 to tank2 is q_1(cm^3/min), and the volumetric flow rate from tank2 is q_o(cm^3/min). The height of the liquid level is h_1 (cm) in tank1 and h_2 in tank2 (cm). Both tanks have the same cross sectional area denotes the area of tank1 is A_1 (cm^2) and area of tank2 is A_2(cm^2).

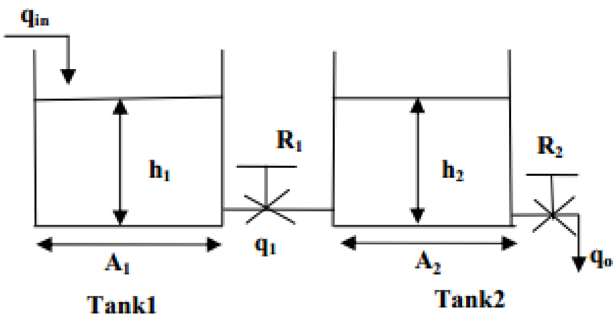

Figure 1. The block diagram of two interacting liquid tanks

For tank 1

$$A_1 \frac{dh_1}{dt} = q_{in-} q_1 \quad (1)$$

Assumimg linear resistance to flow we have:

$$q_1 = \frac{h_1 - h_2}{R_1} \quad (2)$$

And

$$A_1 \frac{dh_1}{dt} = q_{in} - \frac{h_1 - h_2}{R_1} \quad (3)$$

$$R_1 A_1 \frac{dh_1}{dt} = R_1 q_{in} - h_1 + h_2 \quad (4)$$

Taking Laplace transform on both sides of equation (4) then:

$$R_1 A_1 S h_1(s) + h_1(s) - h_2(s) = R_1 q_{in}(s) \quad (5)$$

Or

$$h_1(s)(R_1 A_1 S + 1) - h_2(s) = R_1 q_{in}(s) \quad (6)$$

For tank 2

$$A_2\frac{dh_2}{dt}=q_{1-}q_o \quad (7)$$

Assuming linear resistance to flow we have:

$$q_o=\frac{h_2}{R_2} \quad (8)$$

$$A_2\frac{dh_2}{dt}=\frac{h_1-h_2}{R_1}-\frac{h_2}{R_2} \quad (9)$$

$$A_2R_2\frac{dh_2}{dt}+h_2+\frac{R_2}{R_1}h_2=\frac{R_2}{R_1}h_1 \quad (10)$$

Taking Laplace transform on both sides of equation (10) we have:

$$R_2A_2Sh_2(s)+h_2(s)+\frac{R_2}{R_1}h_2(s)=\frac{R_2}{R_1}h_1(s) \quad (11)$$

$$h_2(s)(R_2A_2S+\frac{R_2}{R_{1.}}+1)+=\frac{R_2}{R_1}h_1(s) \quad (12)$$

To obtain $\frac{h_2(s)}{q_{in}(s)}$, we have to cancel $h_1(s)$ in equations (5) & (10)

$$h_2(s)(R_2A_2S+\frac{R_2}{R_{1.}}+1)(A_1R_1S+1)-(A_1R_1S+1)\frac{R_2}{R_1}h_1(s)=0$$
$$-h_2(s)\frac{R_2}{R_1}+h_1(s)(A_1R_1S+1)\frac{R_2}{R_1}=q_{in}(s)R_2$$
$$h_2(s)(A_1R_1A_2R_2S^2+A_1R_1S+R_2A_1S+A_2R_2S+1)=R_2q_{in}(s)$$
$$h_2(s)(A_1R_1A_2R_2S^2+A_1R_1S+R_2A_1S+A_2R_2S+1)=R_2q_{in}(s)$$
$$\frac{h_2(s)}{q_{in}(s)}=\frac{R_2}{A_1R_1A_2R_2S^2+S(A_1R_1+R_2A_1+A_2R_2)+1} \quad (13)$$

Using the values of the Parameters shown in table 1 we drived the final transfer function of the system as follows:

$$\frac{h_2(s)}{q_{in}(s)}=\frac{0.01}{6.25S^2+7.5S+1} \quad (14)$$

Table 1. Parameters values for two tank

Parameters	Value	Unit
A_1	250	cm^2
A_2	250	cm^2
R_1	0.01	Cm^2/sec
R_2	0.01	Cm^2/sec
H_1	30	cm
H_2	15	cm

3. SIMULATION RESULT

By nature, liquid level control system design is very mathematically orientated and without the use of computer assistance most design problems are very tedious and become quite lengthy. Computer program, such as Matlab have become an invaluable tool in an engineering environment.

To show the convenience of using MATLAB/SIMULINK software package as a tool to simulate and analyze the behavior of two tanks liquid level control system, the simulations are conducted step by step. The system is simulated and the results are shown in the following subsection.

3.1. Simulation Result without Controller

It may be observe that from figure 2, the liquid will constantly overflow. This situation happen because of this system running without controller to control the Pump speed, so the Pump will continuously pump the liquid out from the tank until it overflow. PID controller must be added to control the liquid level.

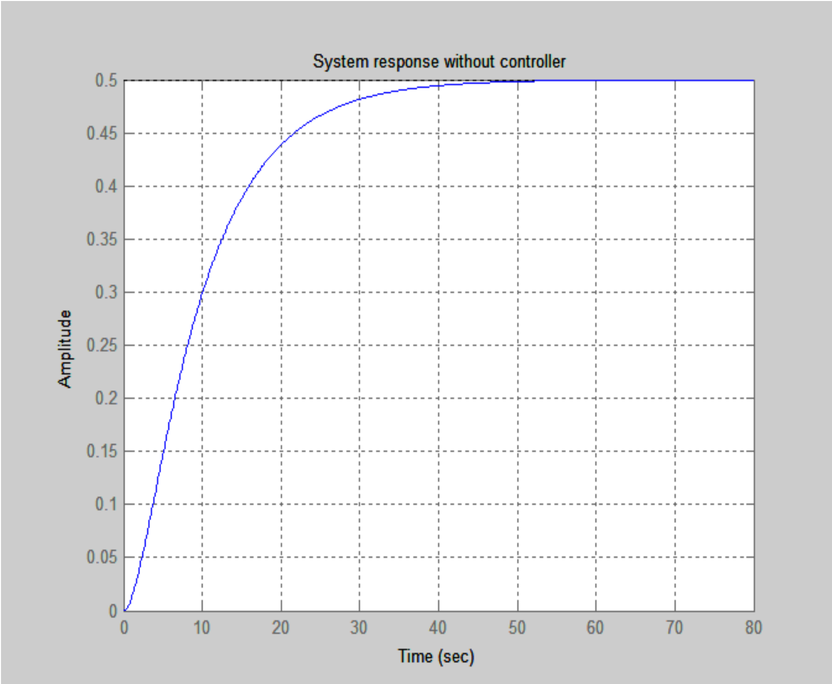

Figure 2. The performance of the coupled tank system without controller

a. Simulation Result with PID Controller:

In this section the simulation result with the PID Controllers has been shown and the controller tunning methode. Figure 3 shows the performance of the system with proportional controller. The set point is set equal to 1 and the proportional gain is set 20. The plot shows that proportional controller reduced both the rise time and the steady state error. Proportional controller also increased the overshoot and decreased the settling time by small amount.

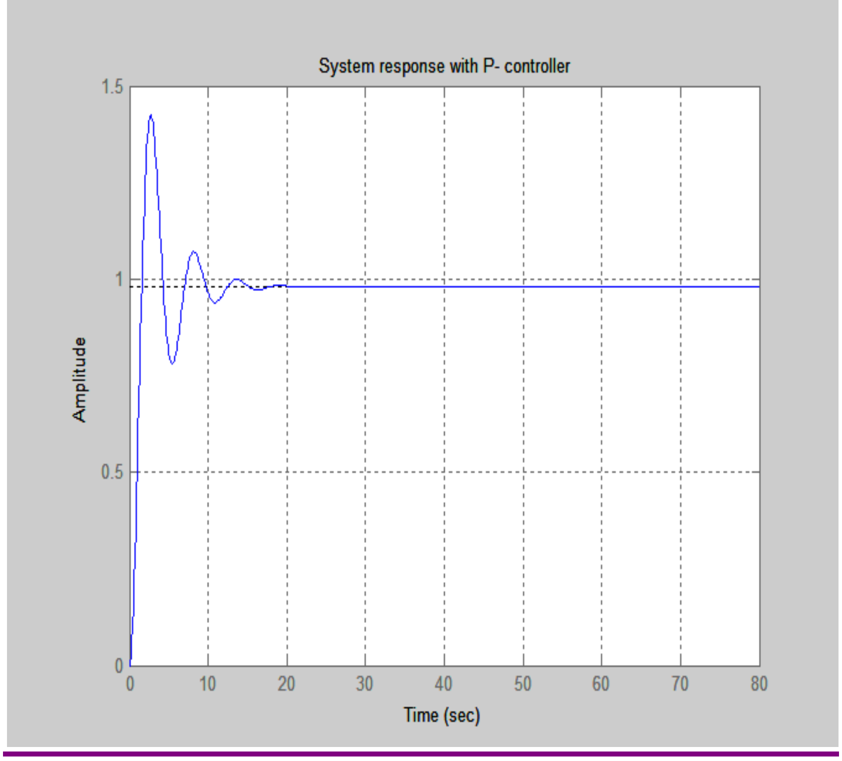

Figure 3. The performance of the coupled tank system with proportional controller

Figure 4 shows the performance of the system with proportional plus derivative controller. The set point is set equal to 1. The proportional gain is set equal to 20 and derivative gain is set equal to 10. This plot shows that the derivative controller reduced both the overshoot and the settling time but had small effect on the rise time and the steady state error.

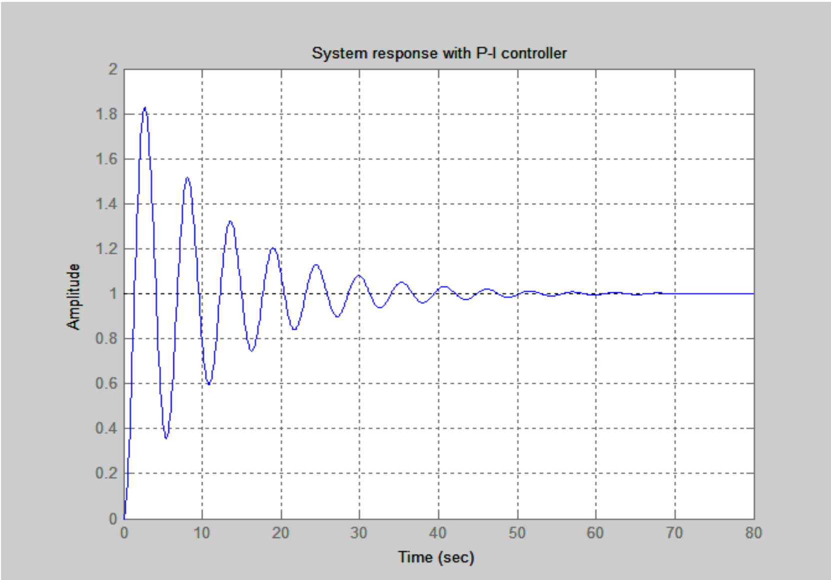

Figure 4. The performance of the coupled tank system with proportional Plus integral controller.

Figure 5 shows the performance of proportional-integral controller. The set point is set equal to 1. The proportional gain is set equal to 20 and integral gain is set equal to 12. The plot shows that integral controller also reduced the rise time increased the overshoot same as the proportional controller does. The integral controller also eliminated the steady state error.

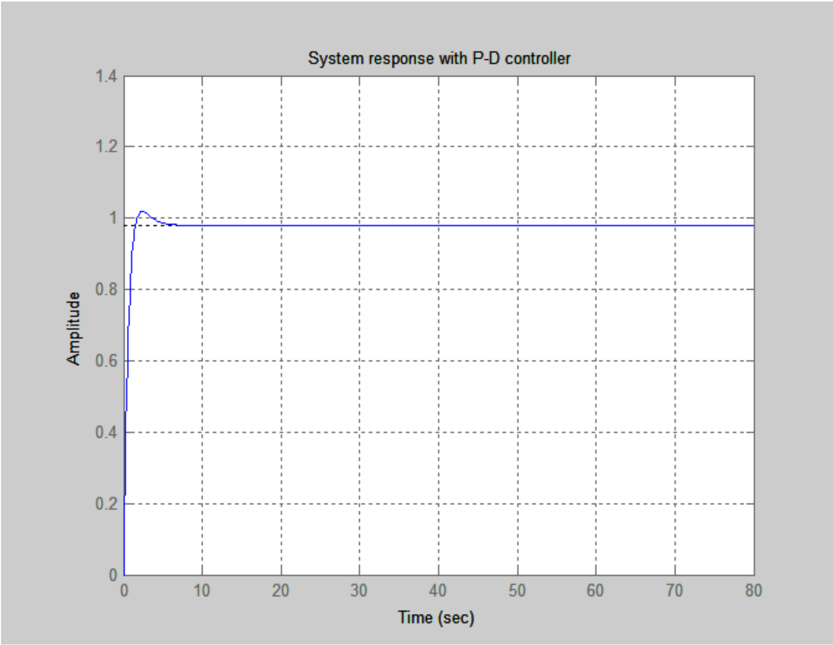

Figure 5. The performance of the coupled tank system with proportional Plus derivative controller

Figure 6 shows the performance of the system with PID Controller. The set point is set equal to 1. The proportional gain is set equal to12, integral gain is set equal to 4 and derivative gain is set equal to 7 to provide the desired response. The plot shows that the output achieves the set point value at time equal to 12 second. The output have slightly overshoot before stabilize at time equal to 20 second.

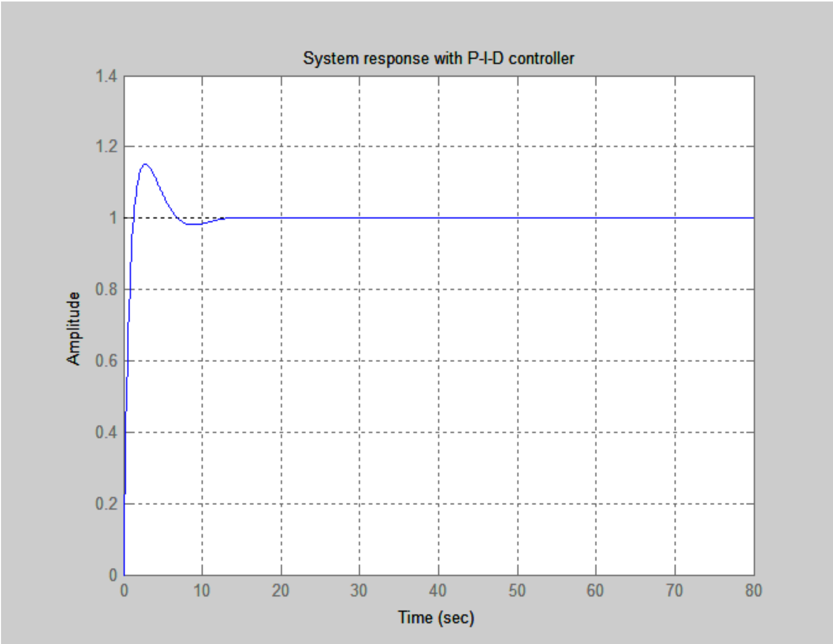

Figure 6. The performance of the coupled tank system with proportional Plus derivative Plus integral controller

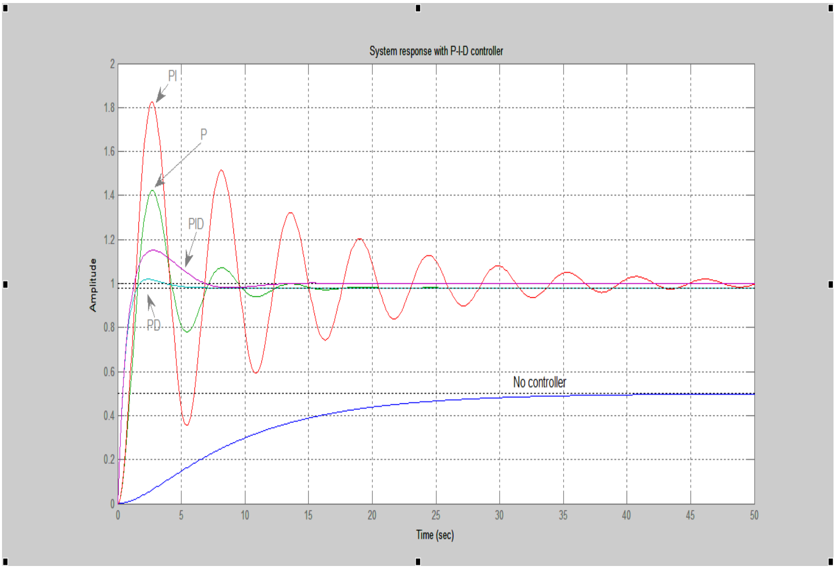

Figure 7. The performance of the coupled tank system with four types of controllers.

From the simulation results shown in figure (2, 3, 4, 5, 6 & 7) it may be concluded that PID controller eliminates the offset of the proportional mode and still provides fast response. This can be used for virtually any process condition including this liquid level control. The PID controller is one of the most powerful but complex controller mode operations combines the proportional, integral, and derivative modes. This system can be used for any process condition including controlling water level in a tank. The water level can be controlled continuously without manual adjusting of the valve. The PID algorithms will automatically response to the system so that the system is stabilized near the set point.

4. CONCLUSION

This paper presents a simulated level control of liquid in two tank system with a different controller's such as Proportional-Integral-Derivative (PID). Various conventional techniques of PID tuning method were tested in order to obtain the PID controller parameters. Simulation was conducted within MATLAB environment to verify the performances of the system in terms of Rise Time, Settling Time, Steady State Error and Overshoot. The liquid level system is controlled using a simple P, PI, PD and PID controller.

Hence it may be concluded that the PID controller is the most effective controller that eliminates the offset of the proportional mode and still provides fast response. That is why PID controller has been chosen. It may be further stated that because of the action of Proportional parameter, the plot result will respond to a step change very quickly. Due to the action of Integral parameter, the system was able to returned to the set point value.

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