

Lab Date:

Number:

Lab Director:

Name Surname:

Group/Subgroup: /

Lab Location: O Block-Otomatic Control Laboratory

Lab Name: Machine Theory 2

Subject: Coupled Tank 1 Level Control with using Feedforward PI Controller

1 INTRODUCTION

The Coupled Tanks plant is a "Two-Tank" module consisting of a pump with a water basin and two tanks. The two tanks are mounted on the front plate such that flow from the first (i.e. upper) tank can flow, through an outlet orifice located at the bottom of the tank, into the second (i.e. lower) tank. Flow from the second tank flows into the main water reservoir. The pump thrusts water vertically to two quick-connect orifices "Out1" and "Out2". The two system variables are directly measured on the Coupled-Tank rig by pressure sensors and available for feedback. They are namely the water levels in tanks 1 and 2. A more detailed description is provided in [5]. To name a few, industrial applications of such Coupled-Tank configurations can be found in the processing system of petrochemical, paper making, and/or water treatment plants.

During the course of this experiment, you will become familiar with the design and pole placement tuning of Proportional- plus-Integral-plus-Feedforward-based water level controllers. In the present laboratory, the Coupled-Tank system is used in two different configurations, namely configuration #1 and configuration #2, as described in [5]. In configuration #1, the objective is to control the water level in the top tank, i.e., tank #1, using the outflow from the pump.

In configuration #2, the challenge is to control the water level in the bottom tank, i.e. tanks #2, from the water flow coming out of the top tank. Configuration #2 is an example of state coupled system.

Topics Covered

- How to mathematically model the Coupled-Tank plant from first principles in order to obtain the two open-loop transfer functions characterizing the system, in the Laplace domain.
- How to linearize the obtained non-linear equation of motion about the quiescent point of operation.
- How to design, through pole placement, a Proportional-plus-Integral-plus-Feedforward-based controller for the Coupled-Tank system in order for it to meet the required design specifications for each configuration.
- How to implement each configuration controller(s) and evaluate its/their actual performance.

Prerequisites

In order to successfully carry out this laboratory, the user should be familiar with the following:

1. See the system requirements in Section 5 for the required hardware and software.
2. Transfer function fundamentals, e.g., obtaining a transfer function from a differential equation.
3. Familiar with designing PID controllers.
4. Basics of Simulink®.
5. Basics of QUARC®.

2 MODELING

2.1 Background

2.1.1 Configuration #1 System Schematics

A schematic of the Coupled-Tank plant is represented in Figure 2.1, below. The Coupled-Tank system's nomenclature is provided in Appendix A. As illustrated in Figure 2.1, the positive direction of vertical level displacement is upwards, with the origin at the bottom of each tank (i.e. corresponding to an empty tank), as represented in Figure 3.2.

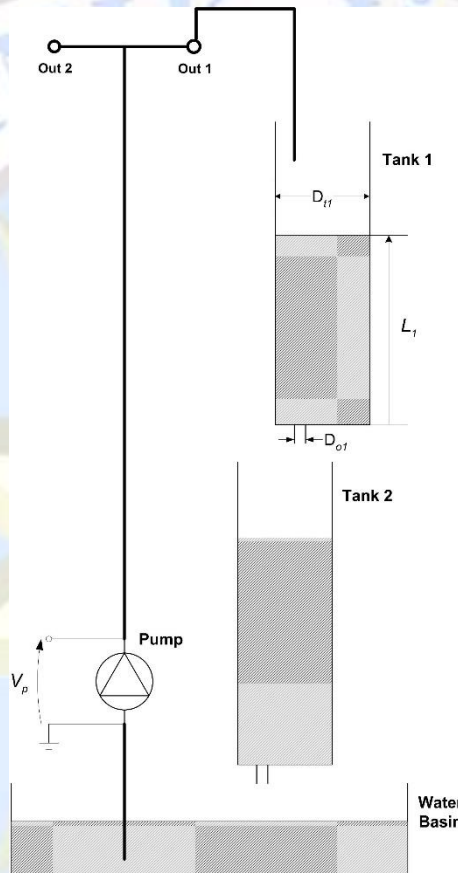


Figure 2.1: Schematic of Coupled Tank in Configuration #1.

2.1.2 Configuration #1 Nonlinear Equation of Motion (EOM)

In order to derive the mathematical model of your Coupled-Tank system in configuration #1, it is reminded that the pump feeds into Tank 1 and that tank 2 is not considered at all. Therefore, the input to the process is the voltage to the pump V_p and its output is the water level in tank 1, L_1 , (i.e. top tank).

The purpose of the present modelling session is to provide you with the system's open-loop transfer function, $G_1(s)$, which in turn will be used to design an appropriate level controller. The obtained Equation of Motion, EOM, should be a function of the system's input and output, as previously defined.

Therefore, you should express the resulting EOM under the following format:

$$\frac{\partial L_1}{\partial t} = f(L_1, V_p)$$

where f denotes a function.

In deriving the Tank 1 EOM the mass balance principle can be applied to the water level in tank 1, i.e.,

$$A_{t1} \frac{\partial L_1}{\partial t} = F_{i1} - F_{o1} \quad (2.1)$$

where A_{t1} is the area of Tank 1. F_{i1} and F_{o1} are the inflow rate and outflow rate, respectively. The volumetric inflow rate to tank 1 is assumed to be directly proportional to the applied pump voltage, such that:

$$F_{i1} = K_p V_p$$

Applying Bernoulli's equation for small orifices, the outflow velocity from tank 1, v_{o1} , can be expressed by the following relationship:

$$v_{o1} = \sqrt{2gL_1}$$

2.1.3 Configuration #1 EOM Linearization and Transfer Function

In order to design and implement a linear level controller for the tank 1 system, the open-loop Laplace transfer function should be derived. However by definition, such a transfer function can only represent the system's dynamics from a linear differential equation. Therefore, the nonlinear EOM of tank 1 should be linearized around a quiescent point of operation. By definition, static equilibrium at a nominal operating point (V_{p0}, L_{10}) is characterized by the Tank 1 level being at a constant position L_{10} due to a constant water flow generated by constant pump voltage V_{p0} .

In the case of the water level in tank 1, the operating range corresponds to small departure heights, L_{11} , and small departure voltages, V_{p1} , from the desired equilibrium point (V_{p0}, L_{10}). Therefore, L_1 and V_p can be expressed as the sum of two quantities, as shown below:

$$L_1 = L_{10} + L_{11}, \quad V_p = V_{p0} + V_{p1} \quad (2.2)$$

The obtained linearized EOM should be a function of the system's small deviations about its equilibrium point (V_{p0}, L_{10}). Therefore, one should express the resulting linear EOM under the following format

$$\frac{\partial}{\partial t} L_{11} = f(L_{11}, V_{p1}) \quad (2.3)$$

where f denotes a function.

Example: Linearizing a Two-Variable Function

Here is an example of how to linearize a two-variable nonlinear function called $f(z)$. Variable z is defined

$$z^T = [z_1 \ z_2]$$

and $f(z)$ is to be linearized about the operating point

$$z_0^T = [a \ b]$$

The linearized function is

$$f_z = f(z_0) + \left(\frac{\partial f(z)}{\partial z_1} \right) \bigg|_{z=z_0} (z_1 - a) + \left(\frac{\partial f(z)}{\partial z_2} \right) \bigg|_{z=z_0} (z_2 - b)$$

For a function, f , of two variables, L_i and V_p , a first-order approximation for small variations at a point (L_1, V_p) (L_{10}, V_{p0}) is given by the following Taylor's series approximation:

$$\frac{\partial^2}{\partial L_1 \partial V_p} f(L_1, V_p) \cong f(L_{10}, V_{p0}) + \left(\frac{\partial}{\partial L_1} f(L_{10}, V_{p0}) \right) (L_1 - L_{10}) + \left(\frac{\partial}{\partial V_p} f(L_{10}, V_{p0}) \right) (V_p - V_{p0}) \quad (2.4)$$

Transfer Function

From the linear equation of motion, the system's open-loop transfer function in the Laplace domain can be defined by the following relationship:

$$G_1(s) = \frac{L_{11}(s)}{V_{p1}(s)} \quad (2.5)$$

The desired open-loop transfer function for the Coupled-Tank's tank 1 system is the following:

$$G_1(s) = \frac{K_{dc1}}{\tau_1 s + 1} \quad (2.6)$$

where K_{dc1} is the open-loop transfer function DC gain, and τ_1 is the time constant.

As a remark, it is obvious that linearized models, such as the Coupled-Tank tank 1's voltage-to-level transfer function, are only approximate models. Therefore, they should be treated as such and used with appropriate caution, that is to say within the valid operating range and/or conditions. However for the scope of this lab, Equation 2.5 is assumed valid over the pump voltage and tank 1 water level entire operating range, V_{ppeak} and L_{1jmax} , respectively.

2.1.4 Configuration #2 System Schematics

A schematic of the Coupled-Tank plant is represented in Figure 2.2, below. The Coupled-Tank system's nomenclature is provided in Appendix A. As illustrated in Figure 2.2, the positive direction of vertical level displacement is upwards, with the origin at the bottom of each tank (i.e. corresponding to an empty tank), as represented in Figure 2.2.

2.1.5 Configuration #2, Nonlinear Equation of Motion (EOM)

This section explains the mathematical model of your Coupled-Tank system in configuration #2, as described in Reference [1]. It is reminded that in configuration #2, the pump feeds into tank 1, which in turn feeds into tank 2. As far as tank 1 is concerned, the same equations as the ones explained in Section 2.1.2 and Section 2.1.3 will apply. However, the water level Equation Of Motion (EOM) in tank 2 still needs to be derived. The input to the tank 2 process is the water level, L_1 , in tank 1 (generating the outflow feeding tank 2) and its output variable is the water level, L_2 , in tank 2 (i.e. bottom tank). The purpose of the present modelling session is to guide you with the system's open-loop transfer function, $G_2(s)$, which in turn will be used to design an appropriate level controller. The obtained EOM should be a function of the system's input and output, as previously defined. Therefore, you should express the resulting EOM under the following format:

$$\frac{\partial L_2}{\partial t} = f(L_2, L_1)$$

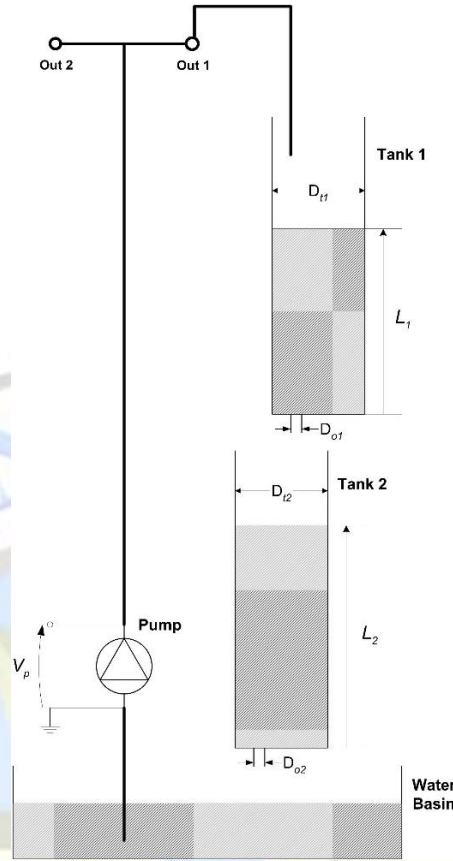


Figure 2.2: Schematic of Coupled Tank in configuration #1.

where f denotes a function.

In deriving the tank #2 EOM the mass balance principle can be applied to the water level in tank 2 as follows

$$F_{i2} = F_{o1}$$

$$A_{t2} \frac{\partial L_2}{\partial t} = F_{i2} - F_{o2}$$

where A_{t2} is the area of tank 2. F_{i2} and F_{o2} are the inflow rate and outflow rate, respectively.

The volumetric inflow rate to tank 2 is equal to the volumetric outflow rate from tank 1, that is to say:

Applying Bernoulli's equation for small orifices, the outflow velocity from tank 2, v_{o2} , can be expressed by the following relationship:

$$v_{o2} = \sqrt{2gL_2}$$

2.1.6 Configuration #2 EOM Linearization and Transfer Function

In order to design and implement a linear level controller for the tank 2 system, the Laplace open-loop transfer function should be derived. However by definition, such a transfer function can only represent the system's dynamics from a linear differential equation. Therefore, the nonlinear EOM of tank 2 should be linearized around a quiescent point of operation. In the case of the water level in tank 2, the operating range corresponds to small departure heights, L_{11} and L_{21} , from the desired

equilibrium point (L_{10}, L_{20}) . Therefore, L_2 and L_1 can be expressed as the sum of two quantities, as shown below:

$$L_2 = L_{20} + L_{21}, \quad L_1 = L_{10} + L_{11} \quad (2.7)$$

The obtained linearized EOM should be a function of the system's small deviations about its equilibrium point (L_{20}, L_{10}) . Therefore, you should express the resulting linear EOM under the following format:

$$\frac{\partial}{\partial t} L_{21} = f(L_{11}, L_{21}) \quad (2.8)$$

where f denotes a function.

For a function, f , of two variables, L_1 and L_2 , a first-order approximation for small variations at a point $(L_1, L_2) = (L_{10}, L_{20})$ is given by the following Taylor's series approximation:

$$\frac{\partial^2}{\partial L_1 \partial L_2} f(L_1, L_2) \cong f(L_{10}, L_{20}) + \left(\frac{\partial}{\partial L_1} f(L_{10}, L_{20}) \right) (L_1 - L_{10}) + \left(\frac{\partial}{\partial L_2} f(L_{10}, L_{20}) \right) (L_2 - L_{20}) \quad (2.9)$$

Transfer Function

From the linear equation of motion, the system's open-loop transfer function in the Laplace domain can be defined by the following relationship:

$$G_2(s) = \frac{L_{21}(s)}{L_{11}(s)} \quad (2.10)$$

$$G_2(s) = \frac{K_{dc2}}{\tau_2 s + 1} \quad (2.11)$$

where K_{dc2} is the open-loop transfer function DC gain, and τ_2 is the time constant.

As a remark, it is obvious that linearized models, such as the Coupled-Tank's tank 2 level-to-level transfer function, are only approximate models. Therefore, they should be treated as such and used with appropriate caution, that is to say within the valid operating range and/or conditions. However for the scope of this lab, Equation 2.10 is assumed valid over tank 1 and tank 2 water level entire range of motion, L_{1_max} and L_{2_max} , respectively.

1.1 Pre-Lab Questions

1. Using the notations and conventions described in Figure 2 derive the Equation Of Motion (EOM) characterizing the dynamics of tank 1. Is the tank 1 system's EOM linear?

Hint: The outflow rate from tank 1, F_{o1} , can be expressed by:

$$F_{o1} = A_{o1} v_{o1} \quad (2.12)$$

2. The nominal pump voltage V_{p0} for the pump-tank 1 pair can be determined at the system's static equilibrium. By definition, static equilibrium at a nominal operating point (V_{p0}, L_{10}) is

characterized by the water in tank 1 being at a constant position level L_{10} due to the constant inflow rate generated by V_{p0} . Express the static equilibrium voltage V_{p0} as a function of the system's desired equilibrium level L_{10} and the pump flow constant K_p . Using the system's specifications given in the Coupled Tanks User Manual ([5]) and the desired design requirements in Section 3.1.1, evaluate V_{p0} parametrically.

3. Linearize tank 1 water level's EOM found in Question #1 about the quiescent operating point (V_{p0}, L_{10}) .
4. Determine from the previously obtained linear equation of motion, the system's open-loop transfer function in the Laplace domain as defined in Equation 2.5 and Equation 2.6. Express the open-loop transfer function DC gain, K_{dc1} , and time constant, t_i , as functions of L_{10} and the system parameters. What is the order and type of the system? Is it stable? Evaluate K_{dc1} and t_i according to system's specifications given in the Coupled Tanks User Manual ([5]) and the desired design requirements in Section 3.1.1.
5. Using the notations and conventions described in Figure 2.2, derive the Equation Of Motion (EOM) characterizing the dynamics of tank 2. Is the tank 2 system's EOM linear?

Hint: The outflow rate from tank 2, F_{o2} , can be expressed by:

$$F_{o2} = A_{o2}v_{o2} \quad (2.13)$$

6. The nominal water level L_{10} for the tank1-tank2 pair can be determined at the system's static equilibrium. By definition, static equilibrium at a nominal operating point (L_{10}, L_{20}) is characterized by the water in tank 2 being at a constant position level L_{20} due to the constant inflow rate generated from the top tank by L_{10} . Express the static equilibrium level L_{10} as a function of the system's desired equilibrium level L_{20} and the system's parameters. Using the system's specifications given in the Coupled Tanks User Manual ([5]) and the desired design requirements in Section 4.1.1, evaluate L_{10} .
7. Linearize tank 2 water level's EOM found in Question #5 about the quiescent operating point (L_{10}, L_{20}) .
8. Determine from the previously obtained linear equation of motion, the system's open-loop transfer function in the Laplace domain, as defined in Equation 2.10 and Equation 2.11. Express the open-loop transfer function DC gain, K_{dc2} , and time constant, t_2 , as functions of L_{10} , L_{20} , and the system parameters. What is the order and type of the system? Is it stable? Evaluate K_{dc2} and t_2 according to system's specifications given in the Coupled Tanks User Manual ([5]) and the desired design requirements in Section 4.1.1.

3. TANK 1 LEVEL CONTROL

3.1. Background

3.1.1. Specifications

In configuration #1, a control is designed to regulate the water level (or height) of tank#1 using the pump voltage. The control is based on a Proportional-Integral-Feedforward scheme (PI-FF). Given a ± 1 cm square wave level set point (about the operating point), the level in tank 1 should satisfy the following design performance requirements:

1. Operating level in tank 1 at 15 cm: $L_{10} = 15$ cm.
2. Percent overshoot less than 10%: $PO_1 < 11\%$.

3. 2% settling time less than 5 seconds: $t_{s_{-1}} < 5.0$ s.
4. No steady-state error: $e_{ss} = 0$ cm.

3.1.2. Tank 1 Level Controller Design: Pole Placement

For zero steady-state error, tank 1 water level is controlled by means of a Proportional-plus-Integral (PI) closed-loop scheme with the addition of a feedforward action, as illustrated in Figure 3.1, below, the voltage feedforward action is characterized by:

$$V_{p_ff} = K_{ff_1} \sqrt{L_{r_1}} \quad (3.1)$$

and

$$V_p = V_{p1} + V_{p_ff} \quad (3.2)$$

As it can be seen in Figure 3.1, the feedforward action is necessary since the PI control system is designed to compensate for small variations (a.k.a. disturbances) from the linearized operating point (V_{p0} , L_{10}). In other words, while the feedforward action compensates for the water withdrawal (due to gravity) through tank 1 bottom outlet orifice, the PI controller compensates for dynamic disturbances.

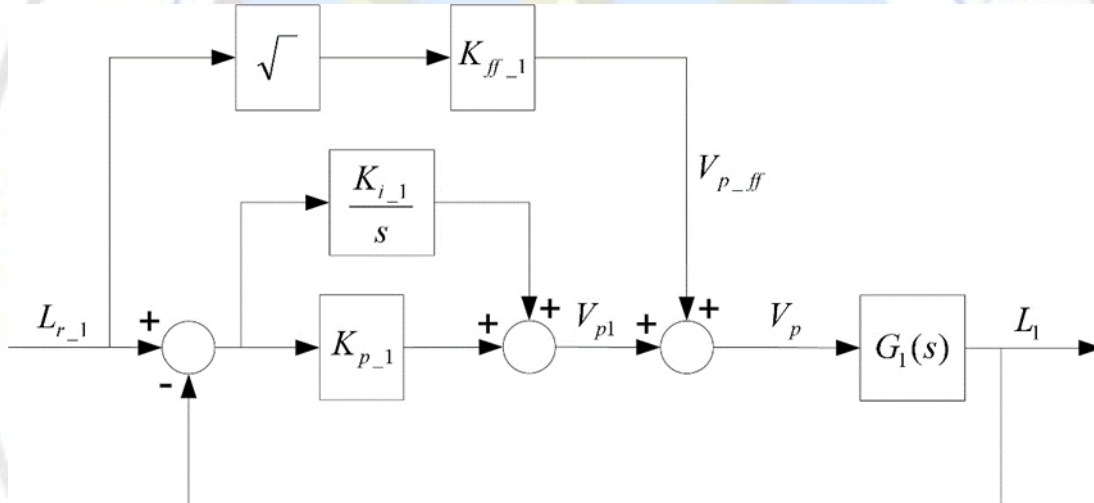


Figure 3.1: Tank 1 Water Level PI-plus-Feedforward Control Loop.

The open-loop transfer function $G_1(s)$ takes into account the dynamics of the tank 1 water level loop, as characterized by Equation 2.5. However, due to the presence of the feedforward loop, $G_1(s)$ can also be written as follows:

$$G_1(s) = \frac{L_1(s)}{V_{p1}(s)} \quad (3.3)$$

3.1.3. Second-Order Response

The block diagram shown in Figure 3.2 is a general unity feedback system with compensator, i.e., controller $C(s)$ and a transfer function representing the plant, $P(s)$. The measured output, $Y(s)$, is supposed to track the reference signal $R(s)$ and the tracking has to match to certain desired specifications.

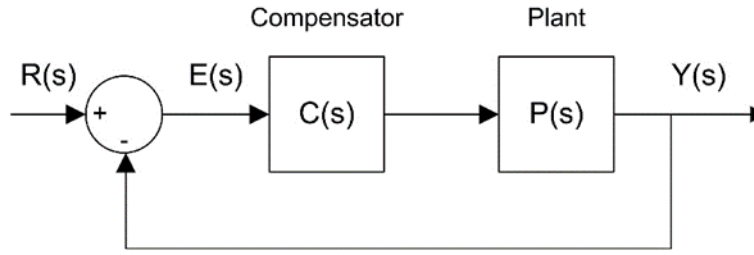


Figure 3.2: Unity feedback system.

The output of this system can be written as:

$$Y(s) = C(s) P(s) (R(s) - Y(s))$$

By solving for $Y(s)$, we can find the closed-loop transfer function:

$$\frac{Y(s)}{R(s)} = \frac{C(s) P(s)}{1 + C(s) P(s)}$$

The input-output relation in the time-domain for a proportional-integral (PI) controller is

$$u = K_p(r - y) + \frac{K_i(r - y)}{s} \quad (3.4)$$

where K_p is the proportional gain and K_i is the integral gain.

In fact, when a first order system is placed in series with PI compensator in the feedback loop as in Figure 3.2, the resulting closed-loop transfer function can be expressed as:

where ω_n is the natural frequency and Z is the damping ratio. This is called the *standard second-order* transfer function. Its response properties depend on the values of ω_n and Z .

Peak Time and Overshoot

Consider a second-order system as shown in Equation 3.5 subjected to a step input given by

$$R(s) = \frac{R_0}{s} \quad (3.6)$$

with a step amplitude of $R_0 = 1.5$. The system response to this input is shown in Figure 3.3, where the red trace is the response (output), $y(t)$, and the blue trace is the step input $r(t)$.

$$\frac{Y(s)}{R(s)} = \frac{\omega_n^2}{s^2 + 2\zeta \omega_n s + \omega_n^2} \quad (3.5)$$

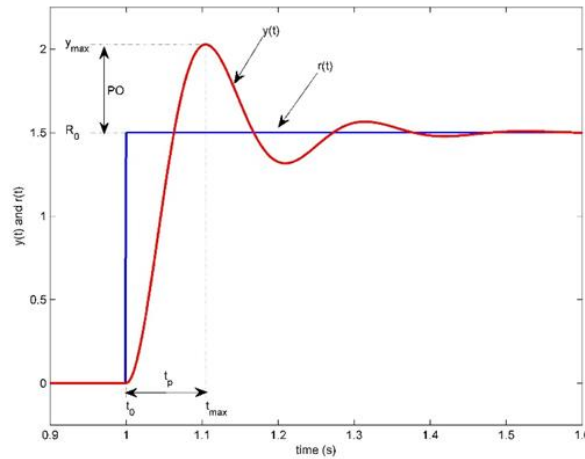


Figure 3.3: Standard second-order step response.

The maximum value of the response is denoted by the variable y_{max} and it occurs at a time t_{max} . For a response similar to Figure 3.3, the percent overshoot is found using

$$PO = \frac{100 (y_{max} - R_0)}{R_0} \quad (3.7)$$

From the initial step time, t_0 , the time it takes for the response to reach its maximum value is

$$t_p = t_{max} - t_0 \quad (3.8)$$

This is called the *peak time* of the system.

In a second-order system, the amount of overshoot depends solely on the damping ratio parameter and it can be calculated using the equation

$$PO = 100 e^{\left(-\frac{\pi \zeta}{\sqrt{1-\zeta^2}}\right)} \quad (3.9)$$

The peak time depends on both the damping ratio and natural frequency of the system and it can be derived as

$$t_p = \frac{\pi}{\omega_n \sqrt{1-\zeta^2}} \quad (3.10)$$

Tank 1 level response 2% Settling Time can be expressed as follows:

$$t_s = \frac{4}{\zeta \omega} \quad (3.11)$$

Generally speaking, the damping ratio affects the shape of the response while the natural frequency affects the speed of the response.

3.2. Pre-Lab Questions

1. Analyze tank 1 water level closed-loop system at the static equilibrium point (V_{p0}, L_{10}) and determine and evaluate the voltage feedforward gain, K_{ff_1} , as defined by Equation 3.1.
2. Using tank 1 voltage-to-level transfer function $G_1(s)$ determined in Section 2.2 and the control scheme block diagram illustrated in Figure 3.1, derive the normalized characteristic equation of the water level closed-loop system.

Hint#1: The feedforward gain K_{ff_1} does not influence the system characteristic equation. Therefore, the feedforward action can be neglected for the purpose of determining the denominator of the closed-loop transfer function. Block diagram reduction can be carried out.

Hint#2: The system's normalized characteristic equation should be a function of the PI level controller gains, K_{p_1} , and K_{i_1} , and system's parameters, K_{dc_1} and r_1 .

- By identifying the controller gains K_{p_1} and K_{i_1} , fit the obtained characteristic equation to the second-order standard form expressed below:

$$s^2 + 2\zeta_1\omega_{n1}s + \omega_{n1}^2 = 0 \quad (3.12)$$

Determine K_{p_1} and K_{i_1} as functions of the parameters w_{n1} , C_1 , K_{dc_1} , and t_1 using Equation 3.5.

- Determine the numerical values for K_{p_1} and K_{i_1} in order for the tank 1 system to meet the closed-loop desired specifications, as previously stated.

3.3. Lab Experiments

3.3.1 Objectives

- Tune through pole placement the PI-plus-feedforward controller for the actual water level in tank 1 of the Coupled-Tank system.
- Implement the PI-plus-feedforward control loop for the actual Coupled-Tank's tank 1 level.
- Run the obtained PI-plus-feedforward level controller and compare the actual response against the controller design specifications.
- Run the system's simulation simultaneously, at every sampling period, in order to compare the actual and simulated level responses.

3.3.2 Tank 1 Level Control Simulation

Experimental Setup

The *s_tanks_1* Simulink® diagram shown in Figure 3.4 is used to perform tank 1 level control simulation exercises in this laboratory.

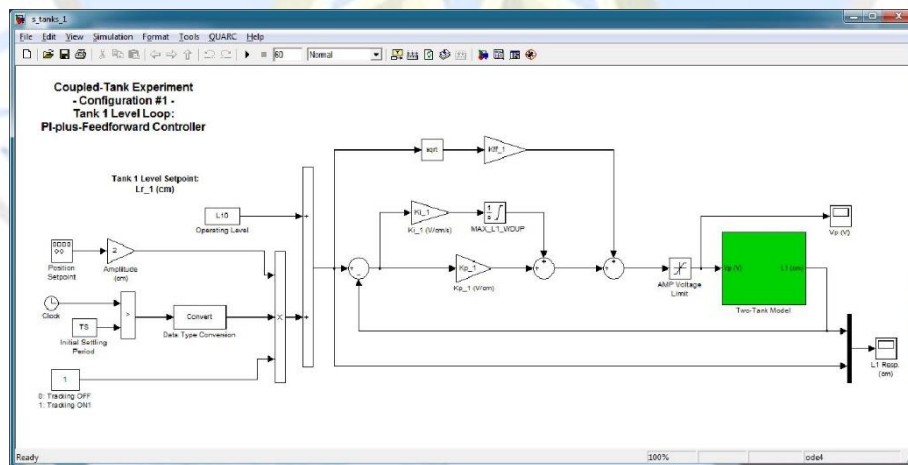


Figure 3.4: Simulink model used to simulate PI-FF control on Coupled Tanks system in configuration #1.

IMPORTANT: Before you can conduct these simulations, you need to make sure that the lab files are configured according to your setup. If they have not been configured already, then you need to go to Section 5 to configure the lab files first.

Follow this procedure:

1. Enter the proportional, integral, and feedforward gain control gains found in Section 3.2 in Matlab as Kp_1 , Ki_1 , and Kff_1 .
 2. To generate a step reference, go to the Signal Generator block and set it to the following:
 - Signal type = *square*
 - Amplitude = 1
 - Frequency = 0.02 Hz
 3. Set the *Amplitude (cm)* gain block to 1 to generate a square wave goes between ± 1 cm.
- COUPLED TANKS Workbook - Student Version
v 1.0
4. Open the pump voltage Vp (V) and tank 1 level response *Tank 1(cm)* scopes.
 5. By default, there should be anti-windup on the Integrator block (i.e., just use the default Integrator block).
 6. Start the simulation. By default, the simulation runs for 60 seconds. The scopes should be displaying responses similar to Figure 3.5. Note that in the *Tank 1 (cm)* scope, the yellow trace is the desired level while the purple trace is the simulated level.

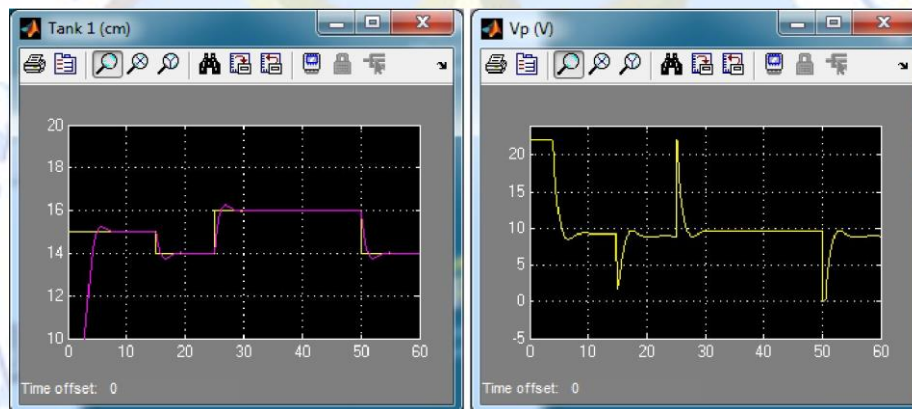


Figure 3.5: Simulated closed-loop configuration #1 control response

7. Generate a Matlab® figure showing the *Simulated Tank 1* response and the pump voltage.

Data Saving: After each simulation run, each scope automatically saves their response to a variable in the Matlab® workspace. The Vp (V) scope saves its response to the variable called `data_Vp` and the *Tank 1 (cm)* scope saves its data to the `data_L1` variable.

 - The `data_L1` variable has the following structure: `data_L1(:,1)` is the time vector, `data_L1(:,2)` is the setpoint, and `data_L1(:,3)` is the simulated level.
 - For the `data_Vp` variable, `data_Vp(:,1)` is the time and `data_Vp(:,2)` is the simulated pump voltage.
8. Assess the actual performance of the level response and compare it to the design requirements. Measure your response actual percent overshoot and settling time. Are the design specifications satisfied? Explain. If your level response does not meet the desired design specifications, review your PI-plus-Feedforward gain calculations and/or alter the closed-loop pole locations until they do. Does the response satisfy the specifications given in Section 3.1.1?

Hint: Use the graph cursors in the *Measure* tab to take measurements.

3.3.3 Tank 1 Level Control Implementation

The *q_tanks_1* Simulink diagram shown in Figure 3.6 is used to perform the tank 1 level control exercises in this laboratory. The *Coupled Tanks* subsystem contains QUARC® blocks that interface with the pump and pressure sensors of the Coupled Tanks system.

Note that a first-order low-pass filter with a cut-off frequency of 2.5 Hz is added to the output signal of the tank 1 level pressure sensor. This filter is necessary to attenuate the high-frequency noise content of the level measurement. Such a measurement noise is mostly created by the sensor's environment consisting of turbulent flow and circulating air bubbles. Although introducing a short delay in the signals, low-pass filtering allows for higher controller gains in the closed-loop system, and therefore for higher performance. Moreover, as a safety watchdog, the controller will stop if the water level in either tank 1 or tank 2 goes beyond 27 cm.

Experimental Setup

The *q_tanks_1* Simulink® diagram shown in Figure 3.6 will be used to run the PI+FF level control on the actual Coupled Tanks system.

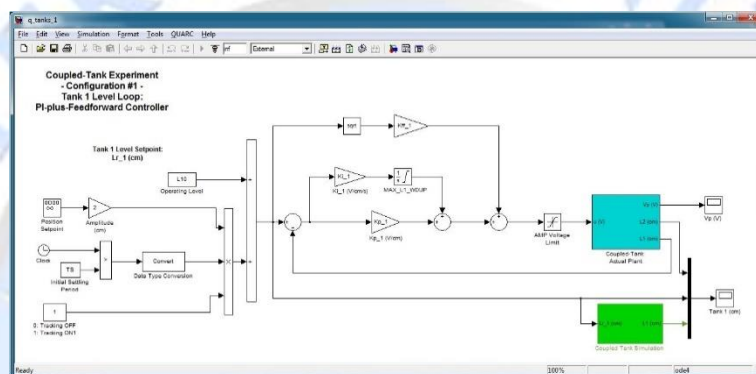


Figure 3.6: Simulink model used to run tank 1 level control on Coupled Tanks system.

IMPORTANT: Before you can conduct these experiments, you need to make sure that the lab files are configured according to your setup. If they have not been configured already, then you need to go to Section 5 to configure the lab files first.

Follow this procedure:

1. Enter the proportional, integral, and feed forward control gains found in Section 3.2 in Matlab® as K_p_1 , K_i_1 , and K_{ff}_1 .
2. To generate a step reference, go to the Signal Generator block and set it to the following:
 - Signal type = *square*
 - Amplitude = 1
 - Frequency = 0.06 Hz
3. Set the *Amplitude (cm)* gain block to 1 to generate a square wave goes between ± 1 cm.
4. Open the pump voltage V_p (V) and tank 1 level response *Tank 1(cm)* scopes.
5. By default, there should be anti-windup on the Integrator block (i.e., just use the default Integrator block).
6. In the Simulink diagram, go to QUARC | Build.
7. Click on QUARC | Start to run the controller. The pump should start running and filling up tank 1 to its operating level, L_{10} . After a settling delay, the water level in tank 1 should begin tracking the ± 1 cm square wave setpoint (about operating level L_{10}).
8. Generate a Matlab® figure showing the *Implemented Tank 1 Control* response and the input pump

voltage.

Data Saving: As in `s_tanks_1.mdl`, after each run each scope automatically saves their response to a variable in the Matlab® workspace.

9. Measure the steady-state error, the percent overshoot and the peak time of the response. Does the response satisfy the specifications given in Section 3.1.1? Hint: Use the `Matlab®ginput` command to take measurements off the figure.

3.4. Results

4. Fill out Table 3.1 with your answers from your control lab results - both simulation and implementation.

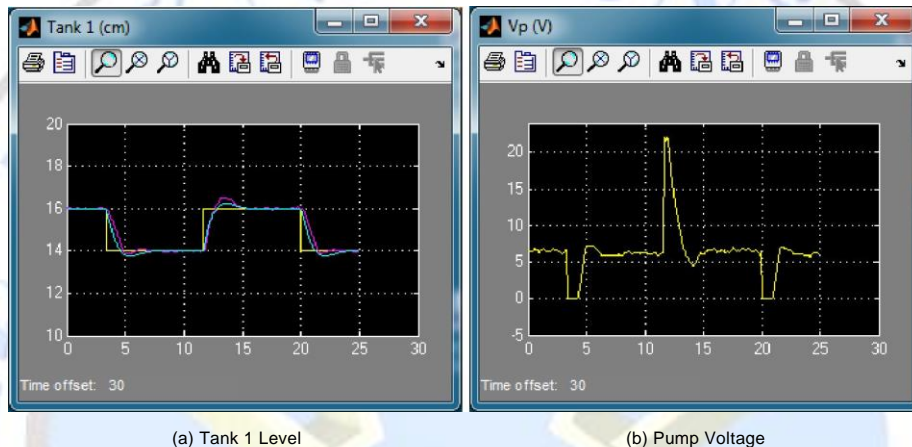


Figure 3.7: Measured closed-loop tank 1 control response

Table 3.1: Tank 1 Level Control Results

Pre Lab Questions			
Tank 1 Control Gains			
Feed Forward Control Gain	$K_{ff\ 1}$		V/A/cm
Proportional Control Gain	$k_p\ 1$		V/cm
Integral Control Gain	$k_i\ 1$		V/(cm.s)
Tank 2 Control Simulation			
Steady-state error	$e_{ss\ 1}$		cm
Settling time	$t_s\ 1$		s
Percent overshoot	POi		%
Tank 2 Control Implementation			
Steady-state error	$e_{ss\ 1}$		cm
Settling time	$t_s\ 1$		s
Percent overshoot	POi		%