MMME2046: Control Laboratory Notes

PI Control of a Single Water Tank Rig

1. Objective

To investigate the open and closed loop dynamics of a single tank fluid rig.

- establish open and closed loop transfer functions and block diagrams
- carry out open and closed loop experiments
- make observations of open and closed loop response

2. Apparatus

The apparatus shown schematically in Figure 1 consists of three main components: A PC running the CE2000 controller software, the CE105 water tank rig, and the CE122 digital interface.

The CE2000 controller software runs on the PC and allows signals to be sent to and from the water tank rig. Controllers can be designed graphically and run from within the CE2000 software.

The CE105 water tank rig houses two coupled water tanks, one of which is the focus of this experiment. Water is pumped via a motorised variable speed pump from the reservoir at the bottom of the rig, through the flow rate sensor, into the water tank. A manual valve allows water to be released from the tank back into the reservoir. A water depth sensor returns a voltage proportional to the depth of water in the tank. Figure 2 shows the layout of the front panel of the water tank rig. This shows the position of visual indicators for water depth and flow rate, along with all the connections for the pump and sensors. In this experiment only tank A is in use, and the additional sensors and pump for tank B are not present.

The CE122 digital interface converts a digital signal from the PC (via the USB cable) to an analogue voltage sent to the variable speed pump (V_m), and converts analogue voltages from the water tank depth sensor (V_h) and flow sensor (V_q) to digital signals sent to the PC.

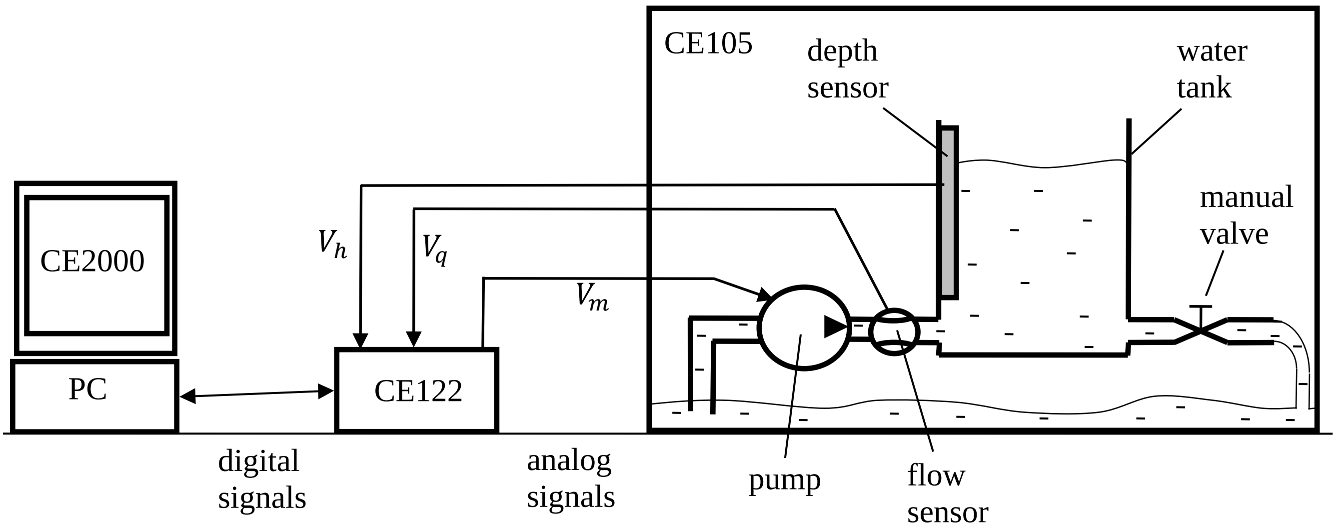

Figure 1 – Schematic of the Water Tank Rig Experiment

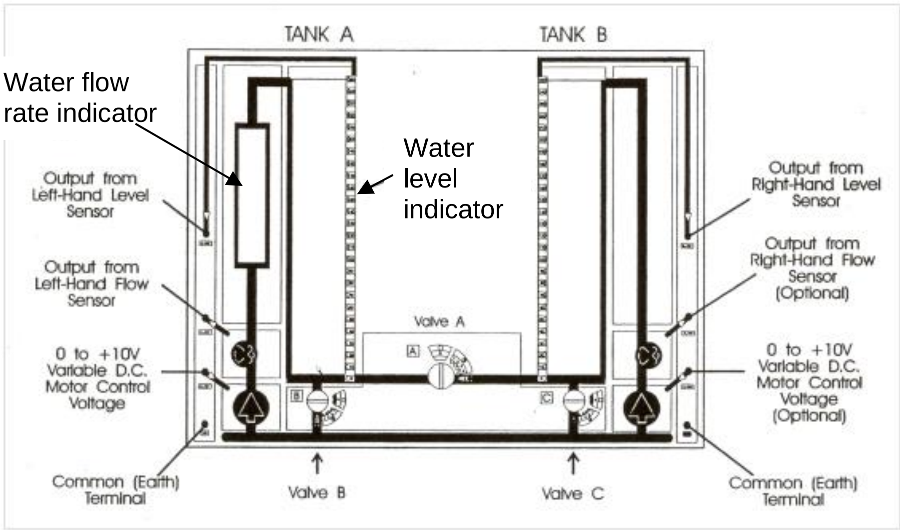

Figure 2 – Layout of the front of the CE105 water tank rig

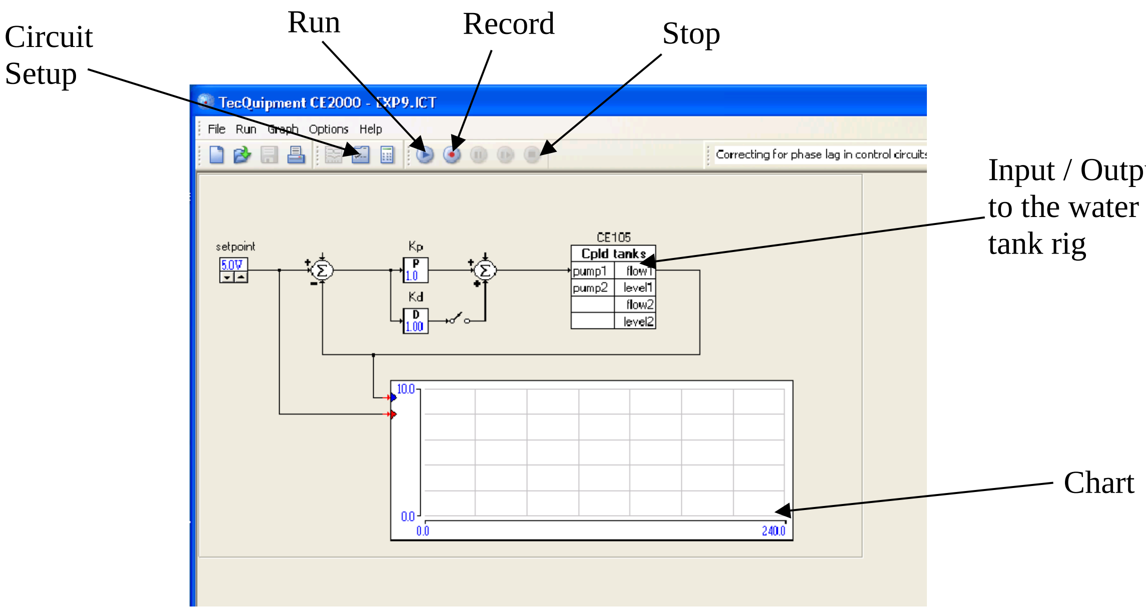

Figure 3 – Typical screenshot of CE2000 software

3 CE2000 Control Software Operation

The water tank rig is operated using the CE2000 software. Figure 3 shows a typical block diagram interface for the rig. The block diagram is made up of elements similar to the block diagrams studied in lectures and includes the special “CE105” block which connects the software to the input & output signals of the rig. The chart block allows signals to be plotted and monitored as the rig is operated. Properties and values in each block can be changed by double clicking on the block. The buttons labeled in Figure 3 are described below:

Run starts the operation of the CE2000 software. Whatever voltage signal is specified to be sent to the pump in the block diagram is sent to the real pump on the rig. Voltage signals from the sensors are returned to the “CE105” block in the block diagram.

Stop stops the operation of the CE2000 software. The CE122 digital interface will maintain the last signal it receives – the signal must be set to zero before clicking "stop" if you wish to allow the tank to drain.

Record records any signals collected on charts or meters in the CE2000 block diagram into a data file. The software will collect up to a maximum of 5 series of data into one data file (i.e. 5 presses of "record" before the data file is full). The number of available series left in the data file can be found by clicking on the "Circuit Setup" button and looking under the Recording tab. Here you can also specify the length of the data file recordings (in seconds) and delete all or the last series of data. Data files can be exported to .txt format (easily opened in Excel) by clicking on File/Export Data… There is at least one free USB slot on each PC to take data away - DO NOT remove any of the existing USB plugs.

4 Open Loop

In order to gain understanding of the water tank rig dynamics we first look at the open loop system, i.e. the output response of the tank and sensors to an input pump voltage.

4.1 OPEN LOOP EXPERIMENT

1. All experiments in this lab are carried out using tank A only. Ensure that the valve A is closed (0), and valve C open (5) at all times.
2. Set valve B to position 3.
3. If the CE2000 control software is not already open, click on the "Tecquipmet CE2000" icon.
4. Click File/Open circuit..., and open "Control_Lab_OL.ict". This will bring up the open loop block diagram interface for the water tank rig. The block diagram interface is set up to send a constant voltage to the water tank rig pump, and measure / record the return voltages from the sensors.
5. Set the V_m voltage sent to the pump to 6V (If your tank has a different voltage written on it use that; ask the demonstrator if you have questions on which value to use).
6. Click on "Record" to start the software operating and record the data. Let the water level settle (this will take up to 15 minutes! Running time is shown at the bottom of the screen). The software will automatically stop after collecting data for 900 seconds.
7. Take this opportunity while waiting for the water level to settle to look at the open loop modelling (section 4.2) and start working on the open loop modelling tasks (section 4.3).
8. When the previous test has finished, click on "Play" to start the software operating again.
9. Set valve B to position 2.5. Observe the effect this has on the water level and note down the water level after it has settled down after a few minutes.
10. Set valve B back to position 3. Attempt to adjust the pump voltage manually in the CE2000 software in order to maintain a constant water level of 150mm for more than one minute. Make notes of any comments on problems or difficulties achieving this.
11. Set the pump voltage V_m to 0V and click "Stop" to allow the tank to drain.
12. Export your recorded data file to a text file (File/Export Data File... - create a new directory for your group).

4.2 Open Loop Modelling

The open loop system is shown in Figure 4, and can be modelled by analysing each individual part of the overall open loop system.

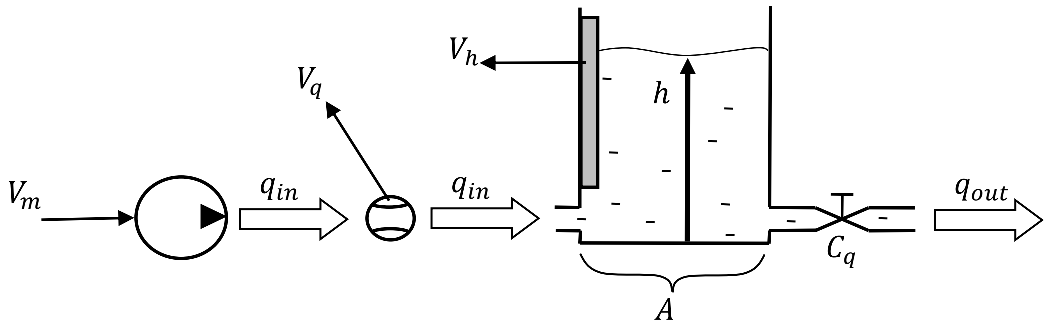

Figure 4 – Open loop system

h	is the height of the water in the tank
q_{in}	is the flow rate into the tank (proportional to the voltage applied to the pump, V_m)
q_{out}	is the flow rate out of the tank (dependent on the manual valve position)
V_m	is the voltage delivered to the motorised variable speed pump
V_q	is the voltage returned by the flow rate sensor (proportional to the flow rate in, q_{in})
V_h	is the voltage returned by the water level sensor (proportional to the water height, h)
A	is the cross sectional area of the tank = $9.35 \times 10^{-3}\ m^2$
C_q	is the linearised flow constant of the manual valve (flow is assumed proportional to h and the characteristic of the valve is linearised) $= ??\ (cm^3/min)/m$
K_m	is the constant of proportionality for the pump $= 500\ (cm^3/min)/V$
K_q	is the constant of proportionality for the flow rate sensor $= 0.00227\ V/(cm^3/min)$
K_h	is the constant of proportionality for the water level sensor $= 40\ V/m$

Table 1 – Parameters and values used in the open loop modelling

The open loop system can be represented by a block diagram of the form shown in Figure 5.

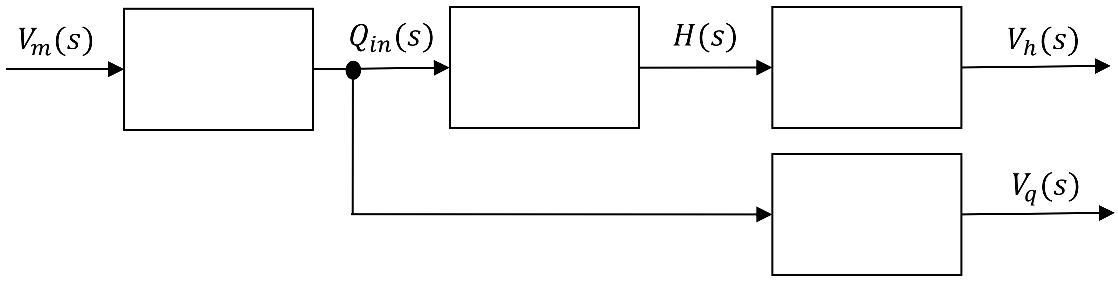

Figure 5 – Block diagram for the open loop system

4.3 OPEN LOOP MODELLING TASKS

To be carried out during the lab, and necessary for your lab report.

1. Derive the transfer functions for the blank blocks shown in Figure 5.
2. Derive the overall open loop transfer function for the water tank height $\left(G_P(s) = \frac{H(s)}{V_m(s)}\right)$.

Hints: Use the constants and information in table 1. The dynamics of the water tank can be found by applying the continuity equation:

$$q_{in} - q_{out} = rate\ of\ change\ of\ water\ in\ tank$$

5 Closed Loop

A controller is applied to the open loop system which aims to maintain a constant water tank height. A proportional plus integral plus differential (P+I+D) controller is used in this experiment, which has a transfer function given by:

$$G_c(s) = sK_d + K_p + \frac{K_I}{s}$$

5.1 CLOSED LOOP EXPERIMENT

1. All experiments in this lab are carried out using tank A only. Ensure that the valve A is closed (0), and valve C open (5) at all times.
2. Click File/Open circuit..., and open “Control_Lab_CL.ict”. This will bring up the closed loop block diagram interface for the water tank rig.
3. The block diagram interface implements the P+I controller as described above. The gains K_p and K_I can be altered by clicking on the appropriate block. Throughout this experiment a desired reference height of 150mm is applied to the controller (assumed to correspond to 6V reference voltage V_r).
4. For test number 1 (see table 2), set valve B position to 3, the proportional gain in the P block to 3 and ensure that there is no integral gain (open the switch after the I block).
5. Click on “Record” to start the software operating and record the data from the sensors. Recording time is set to 600s (10 minutes) and recording will stop automatically after this.
6. Observe and takes notes about the closed loop response of the system. You may opt to stop recording once the system has reached steady state,
7. Set V_r to 0V and click “Play” to zero the voltage sent to the pump.
8. Allow the tank to drain completely, then click “Stop”.
9. Reset V_r to 6V ready for the next test.
10. Apply the appropriate values for K_P, K_I, K_D and valve B position for each test in the table below and follow through steps 6 to 10 for each test.
11. Export your recorded data file to a text file (File/Export Data File...).

Test Number	Proportional Gain, K_P	Integral Gain, K_I	Differential Gain K_D	Valve B Position
1	3	none	None	3
2	3	none	10	3
3	6	none	none	3
4	3	1	none	3
5	3	2	none	3
6	3	4	none	3

Table 2 – Closed loop test values

5.2 Closed Loop Modelling

The closed loop system can be represented by a block diagram of the form shown in Figure 6. The feedback signal is the height sensor voltage, which must be compared to a reference voltage, V_r, to form the error voltage, V_e. The controller acts on the error voltage to produce a voltage supplied to the pump which aims to reduce the error (i.e. control the water height h towards the desired reference height h_r)

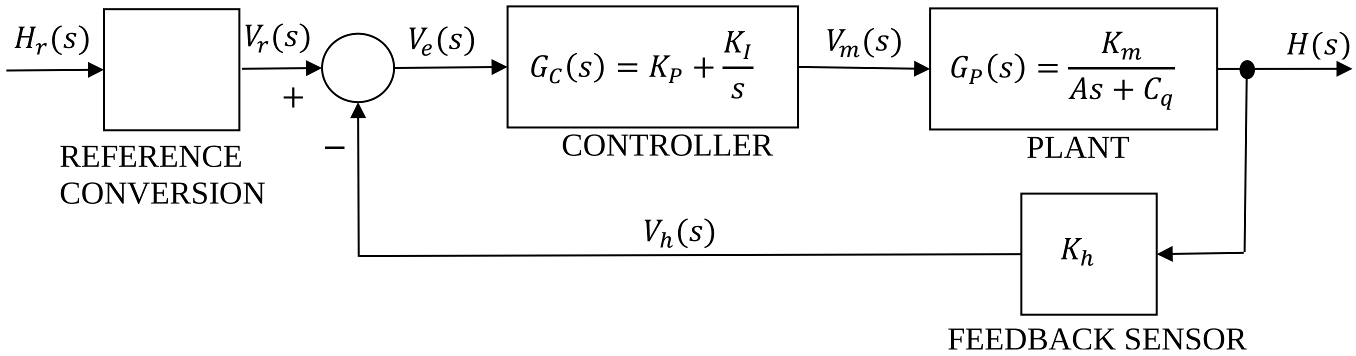

Figure 6 – Block diagram for the closed loop system

5.3 CLOSED LOOP MODELLING TASKS

To be carried out during the lab, and to be included with your lab report.

1. What transfer function needs to go in the "Reference Conversion" block in Figure 6 to ensure the correct reference voltage is compared to the water level sensor voltage?
2. Derive the overall transfer function for the closed loop system $\left(G_{CL}(s) = \frac{H(s)}{H_r(s)}\right)$.

Hints: Start with the output signal $H(s)$ and work back through the blocks. The definition of a transfer function is the ratio of the Laplace of the output signal to the Laplace of the input.

Laboratory Report:

1) Open loop experiment:
   a) Draw the full block diagram for the open loop system as given in figure 5, with the correct transfer functions for each of the blank blocks.
   b) Plot one graph of the water level sensor voltage and the pump voltage against time for a step input to the system with the outflow valve set to position 3.
   c) If the system has a transfer function of the form $G_P(s) = \frac{H(s)}{V_m(s)} = \frac{\mu}{1+Ts}$ where µ is the gain and T is the time constant, calculate values for µ and T for the case where the valve is at position 3.
   d) Calculate a value for C_q in $cm^3 min^{-1} mm^{-1}$.
   e) Comment on any difficulties you had in maintaining a level of 150mm.

2) Closed loop experiment:
   a) Plot one graph of the water level sensor voltage and the pump voltage against time for a step input to the system for test numbers 1,2, and 3. Is it possible to completely eliminate steady state error using just proportional and differential control?
   b) Plot one graph of the water level sensor voltage and the pump voltage against time for a step input to the system for test numbers 4,5, and 6.
   c) Comment on the effect of integral control on the steady state error and the system behaviour.
   d) Comment on the effect of differential control on the system behaviour.
   e) If the system response for test 6 has the Laplace transform $H(s) = \frac{A}{s(s^2+2\gamma\omega_n s+\omega_n^2)}$, estimate values for ω_n and γ.

Mark Breakdown:

System Modelling	45
Results	45
Presentation	10