Process Control/
Level Control

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Objectives

- The following experiments are designed to allow the exploration of different types of process controllers.
- Response time effects of Proportional Band, Integral time constant, Derivative time constant, and combinations of each will be studied.
- Properties of Proportional, Proportional-Integral, Proportional-Derivative, and Proportional-Integral-Derivative controllers will be explored.
- Optimization of the process controller using the Ziegler-Nichols method and an Impulse-Tune method will be conducted.

Introduction

The following is simply a brief review of what was learned in process control. There are three major components in a controller that affect the response time. The Proportional Band is a variable that controls how long it takes for a proportional response. The Proportional Band is used in the following formula to determine the proportional time constant K_c:

$$K_c = \frac{100}{pb(\%)} \tag{1}$$

The response for liquid level in a tank when regulated by a Proportional (P) controller is governed by equation 2:

$$H = K_c \varepsilon + H_s \tag{2}$$

H is the height of the tank, K_c is the proportional constant, ε is the difference between the measured height and the set point, and H_s is the steady state height of the tank.

In a Proportional-Derivative (PD) controller a new element, derivative action, is introduced. Derivative action is regulated by the instantaneous change in the height with respect to time. When derivative action is included in equation 2 we get equation 3:

$$H = K_c \varepsilon + K_c \tau_D \frac{d\varepsilon}{dt} + H_s \tag{3}$$

H is the height of the tank, K_c is the proportional constant, ε is the difference between the measured height and the set point, τ_D is the derivative time constant, and H_s is the steady state height of the tank.

In a Proportional-Integral (PI) controller integral action is introduced. Integral action us regulated by integrating the change in height with respect to a change in time. When integral action is added to a proportional controller we get equation 4:

$$H = K_c \varepsilon + \frac{K_c}{\tau_I} \int_0^t \varepsilon \, dt + H_s \tag{4}$$

H is the height of the tank, K_c is the proportional constant, ε is the difference between the measured height and the set point, τ_I is the integral time constant, and H_s is the steady state height of the tank.

A good controller usually is a combination of all three components. The equation that governs the response of a PID controller is given in equation 5:

$$H = K_c \varepsilon + \frac{K_c}{\tau_I}\int_0^t \varepsilon \, dt + K_c \tau_D \frac{d\varepsilon}{dt} + H_s \qquad (5)$$

When dealing with controllers optimization is very important. In this project optimization will be completed using two methods. The Impulse-Tune method and the Ziegler-Nichols method are described later in the procedure. The Ziegler-Nichols method is governed by the rules outlines in Table 1.

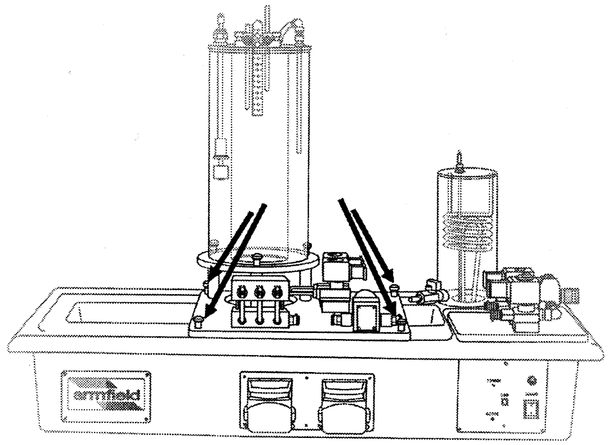
Table 1. Z-N tuning rules. K_u and P_u are the ultimate gain and ultimate period obtained in Experiment D. [1]

Type of Control	**K_c**	**τ_I**	**τ_D**
Proportional	0.5*K_u		
Prop-Integral	0.45*K_u	P_u/1.2	
Prop-Int-Der	0.6*K_u	P_u/2	P_u/8

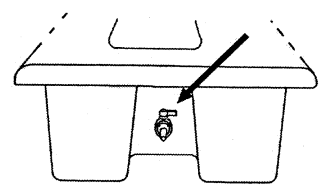
[1]. Coughanowr, Donald. Process Systems Analysis and Control. 2nd ed. McGraw Hill, 1991.

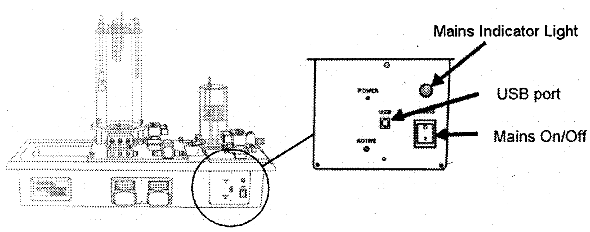
Equipment

The process control unit is mounted on a blue plastic vat and the water tank for level control experiments is fastened by thumb nuts.



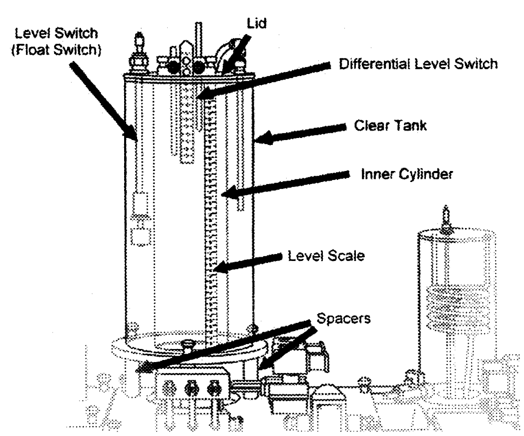
The vat includes a drainage channel with a drain valve located on the left side of the vat. The valve is connected to the drain via a tube and the valve should be left open at all times and the tube must be leading to a sink at all times.



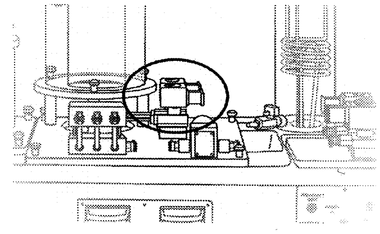


The front of the unit has a connector for a USB cable and an on/off switch. The USB should be connected at all times and before staring the experiments the unit needs to be switched ON. NOTE: Some of the light diodes on the front may still be lit even if the power is OFF.

The large acrylic vessel is the tank where the level control will be carried out. The tank has a number of switches inside it, including a float switch and a differential level switch. These switches are not used in the experiments but you are encouraged to test the functionality of each switch. Tappings in the base of the vessel allow connections to solenoids and pumps. A vertical overflow tube is included as a safety feature.



Finally there are two solenoids connected the acrylic vessel. These are normally closed and are labeled SOL2 and SOL3. These need to be connected by tubes to the sink at all times. The solenoids are used to introduce disturbances in the system as will be described below.



The process control unit is connected to a PC via the USB cable. From the PC the software to control the instrument is run. Please spend some time to familiarize yourself with the software and the functions. The software allow for recording and plotting the data in every experiment and you need to store your own data as separate files.

For a more thorough description of the equipment please refer to the manual and to the help-file in the software.

Procedure

Introduction to the level control instrument.

Make sure that the water inlet to the instrument is turned on. This is a cold water tap located behind the instrument and connected via a tube to the inlet and the filter on the left side of the instrument.

Make sure the instrument is turned ON.

Start the software from the shortcut PCT40 located on the desktop of the PC. Chose section 1 and click "Load" in the bottom left corner.

Feel free to familiarize yourself with the software and the different windows in the program. Once you are ready select the 'view diagram', the grey icon under the 'Format' drop down menu. This takes you into the mimic diagram screen. Check that 'On/Off – Solenoid 1' is set to 'Controller'.

Select 'Configure' from the Sample menu, and set sampling to Automatic at intervals of 5 seconds, with duration as Continuous.

Fixed (manually set) ratio
In the PCT40 software select 'Control' below the Tank Level sensor display, to open the PID controller window.

Set P, I and D to 0.

In Manual Operation set 'Manual Output' to the percentage time during which the control valve will be open. 50% is suggested as a starting value.

At the bottom left, set the Cycle Time to 10s- this is the time over which the control percentage will be applied (i.e. for a percentage of 50% and a cycle time of 10s, the valve will be switched on for 5s and switched off for 5s).

In the Mode of Operation select the 'Manual Control' radio button and click on 'Apply'. The valve should begin to operate intermittently as the time proportional controller sends signals to control it.

Close the drain valve at the base of the large process vessel, preventing flow out of the vessel. The vessel will begin to fill with water. When the fluid level reaches 200mm, partially open the valve to allow water to drain slowly from the vessel.

Check that there is a new data sheet for data logging. The leftmost icon under the 'File' drop down menu allows you to start a new file. Clicking the icon between the 'GO' and the 'wrench' will reset the counter and start a new data log but it will not clear the previous result window. This is the 'new result sheet' icon.

Select the 'GO' icon to begin data logging, and observe the fluid level in the process vessel. When the level has changed by more than 50mm, select the 'STOP' icon to finish data logging.

Adjust the control percentage according to the change in fluid level. If the fluid level fell, increase the percentage. If the level rose, decrease it. If the change was rapid, make a change of 15 to 20%. If it was gradual, change the value by 5 or 10%.

Continue to monitor the fluid level and adjust the percentage value until the fluid maintains a constant level.

Create a new results sheet by selecting the ‘new result sheet’ icon in the tool bar of the software.

Select the ‘GO’ icon to begin data logging, and log the fluid level for a few minutes. Select the ’STOP’ icon to finish data logging.

Make a note of the settings used.

On the software screen, select the control switches for valves SOL2 and SOL3, opening the valves and allowing water to drain from the vessel until the water level is approximately 150mm.

Close SOL2 and SOL3 again.

Create a new results sheet by selecting the ‘new result sheet’ icon in the tool bar of the software.

<u>Controller-controlled time proportioning</u>
In the PCT40 software, open the PID controller window.

Set the Set Point to 200mm.

Set P to 40%.

Leave I and D set to 0.

The Manual Control setting may be ignored.

Leave the Cycle Time at 10s.

In the Mode of Operation select the Automatic Control radio button and click on ‘Apply’. The valve should begin to operate intermittently as the time proportional controller sends signals to control it.

Select the ‘GO’ icon to begin data logging, and observe the fluid level in the process vessel. Note the behavior of SOL1 as the fluid level approaches the Set Point. When the oscillations around the Set Point have settled, select the ‘STOP’ icon to finish data logging.

<u>Disturbances</u>
Within the software it is possible to introduce disturbances in the outflow from the vessel by opening the Normally Closed solenoid valves SOL 2 and SOL 3:

Create a new results sheet by selecting the ‘new result sheet’ icon in the tool bar of the software.

Select the ‘GO’ icon to begin data logging.

In the software, select the switch to open valve SOL 2. Listen to the switch clicking on the instrument and make sure the water drains into the sink.

In the Manual Operation section of the PID control window, modify the ‘Manual Output’ percentage value until the fluid level is maintained at a constant value

Open valve SOL 3. Both valves SOL2 and SOL3 should now be open. As before, modify the ‘Manual Output’ percentage value to maintain the fluid level in the process vessel, and note any problems with maintaining this level.

Close both valves SOL2 and SOL3 and set the ‘Manual Output’ percentage value back to the setting it was at the start of this section of the exercise. Note whether this value still maintains the fluid level as before.

Select the ‘STOP’ icon to finish data logging.

Do not close the drain valve on the bottom of the vessel. This valve needs to remain partially open for the other experiments.

You should now be familiar with some of the controls of the instrument, how to introduce disturbances, fill up and empty the vessel with water and how to log your data.

<u>**NOTE:**</u> In the following experiments it is important that you log the data that you produce. There are no explicit instructions in the procedure do to this but it is assumed that you are now proficient with using the software to collect the data you need.

<u>Experiment A – Proportional Controller</u>

1. Start with an empty vessel or a water level below 100mm.
2. In the controller set the proportional band to 20% and the set point to 150mm. Leave I and D at 0.
3. Observe the behavior of the instrument and wait until the water level does not change anymore.
4. Open SOL3 by clicking the icon.
5. Observe the behavior of the instrument and wait until the water level is stable.
6. Introduce another disturbance by opening SOL2.
7. Observe the behavior of the instrument and wait until the water level is stable.
8. Introduce another disturbance by closing SOL3.
9. Observe the behavior of the instrument and wait until the water level is stable.
10. Close SOL2. The level should return to the set point.
11. Change the set point to 210mm. Note the change and wait for the level to stabilize.
12. Change the set point to 90mm. Note the change and wait for the level to stabilize.
13. Change the set point back to 150 and adjust the proportional band to 10, 4 and 0 (on/off controller) and for each setting of the proportional band repeat the experiments above (from 3 to 12).

Make sure you log your data in such a way that you can collect and later plot this in a comprehensive way for your report.

Experiment B – Proportional Derivative Controller

1. Start with an empty vessel or a water level below 100mm.
2. In the controller set the proportional band to 10%, the derivative time constant (D) to 6 seconds and the set point to 150mm. Leave I at 0.
3. Observe the behavior of the instrument and wait until the water level does not change anymore.
4. Open SOL3 by clicking the icon.
5. Observe the behavior of the instrument and wait until the water level is stable.
6. Introduce another disturbance by opening SOL2.
7. Observe the behavior of the instrument and wait until the water level is stable.
8. Introduce another disturbance by closing SOL3.
9. Observe the behavior of the instrument and wait until the water level is stable.
10. Close SOL2. The level should return to the set point.
11. Change the set point to 210mm. Note the change and wait for the level to stabilize.
12. Change the set point to 90mm. Note the change and wait for the level to stabilize.
13. Change the set point back to 150 and adjust D to 10 and 30 seconds and for each setting of the proportional band repeat the experiments above (from 3 to 12).
14. Change the derivative time constant back to 6 s and change the proportional band to 4%. Repeat steps 3 to 12 above and note the response.

Make sure you log your data in such a way that you can collect and later plot this in a comprehensive way for your report.

Experiment C – Proportional Integral Controller

1. Start with an empty vessel or a water level below 100mm.
2. In the controller set the proportional band to 10%, the integral time constant (I) to 12 seconds and the set point to 150mm. Leave D at 0.
3. Observe the behavior of the instrument and wait until the water level does not change anymore.
4. Open SOL3 by clicking the icon.
5. Observe the behavior of the instrument and wait until the water level is stable.
6. Introduce another disturbance by opening SOL2.
7. Observe the behavior of the instrument and wait until the water level is stable.
8. Introduce another disturbance by closing SOL3.
9. Observe the behavior of the instrument and wait until the water level is stable.
10. Close SOL2. The level should return to the set point.
11. Change the set point to 210mm. Note the change and wait for the level to stabilize.
12. Change the set point to 90mm. Note the change and wait for the level to stabilize.
13. Change the set point back to 150 and adjust I to 30 and 60 seconds and for each setting of the proportional band repeat the experiments above (from 3 to 12).
14. Change the integral time constant back to 12 s and change the proportional band to 4%. Repeat steps 3 to 12 above and note the response.

Make sure you log your data in such a way that you can collect and later plot this in a comprehensive way for your report.

Experiment D – Optimization/Tuning

Ziegler-Nichols tuning

1. Turn off both the derivative (D) and the integral (I) time constants by setting them to zero.
2. Put the set point at 150mm.
3. Set the proportional band to 10% and let the vessel fill up to the set point.
4. Introduce a disturbance by opening SOL3. You will notice some oscillation but the signal will eventually flatten out.
5. Decrease the proportional band by 0.5% and observe the oscillations and if the signal flatten out.
6. Keep decreasing the proportional band by 0.5% until the system oscillated continuously. At this proportional band you can calculate the gain from equation 1. This is the ultimate gain, K_u.
7. Find the period of these oscillations by recording the distance between peaks. This is known as the ultimate period, P_u.
8. Use Table 1 or your process control textbook to find the settings for the optimal proportional band, integral time constant and derivative time constant.

Make sure you log your data in such a way that you can record the values as well as plot this in a comprehensive way for your report.

Impulse-method tuning

1. Turn off both the derivative (D) and the integral (I) time constants by setting them to zero.
2. Set the set point to 0mm and allow the vessel to empty.
3. Set the proportional band to 0%.
4. Set the set point to 150mm.
5. Wait as the fluid rises to the set point and overshoots. Continue to record the data as the fluid level falls again below the set point. Eventually the fluid will start to rise again.
6. From the data determine the peak to peak variation, distance y between the highest value of the overshoot and the lowest value of the undershoot.
7. Record the time between these two values, t.
8. Use the following formulas to optimize the instrument:

   $P = y/3$
   $I = t$
   $D = t/6$

9. This will give you a good start for an optimization but when you use this you may find that there is room for improvement.

Make sure you log your data in such a way that you can record the values as well as plot this in a comprehensive way for your report.

Experiment E – Proportional Integral Derivative Controller

1. Start with an empty vessel or a water level below 100mm.
2. Use the settings obtained for the Z-N optimization in experiment D. Make sure the set point is 150mm.
3. Observe the behavior of the instrument and wait until the water level does not change anymore.
4. Open SOL3 by clicking the icon.
5. Observe the behavior of the instrument and wait until the water level is stable.
6. Introduce another disturbance by opening SOL2.
7. Observe the behavior of the instrument and wait until the water level is stable.
8. Introduce another disturbance by closing SOL3.
9. Observe the behavior of the instrument and wait until the water level is stable.
10. Close SOL2. The level should return to the set point.
11. Change the set point to 210mm. Note the change and wait for the level to stabilize.
12. Change the set point to 90mm. Note the change and wait for the level to stabilize.
13. Change the set point back to 150 and use the Impulse-Method optimization settings obtained in experiment D. Repeat steps 3 to 12 above and note the response.
14. Feel free to experiment by changing the settings and predicting what will happen

Make sure you log your data in such a way that you can collect and later plot this in a comprehensive way for your report.

Data Analysis

- For each experiment discuss the effects of the changes made to each of the settings.
    - Did the response time increase or decrease?
    - Was the response time faster, slower, or the same when the set point was changed?
    - What effects do changes in the Derivative or Integral time constants have?
    - Etc.…
- Discuss the results of the optimization and determine the percent difference between the Ziegler-Nichols and the Impulse-Method settings.