EXPERIMENT 4
PROCESS CONTROL SYSTEMS _ PCT-100

OBJECTIVE
To provide controlled process in a learning environment which reflects the control problems experience in industry and on which students can carry out detailed analysis of alternative control techniques. Also to illustrate simply and clearly, the fundamental control techniques of Proportional (P), Proportional + Integral (PI), Proportional + Integral + Differential (PID) in a Process Control Technology (PCT)-100.

REFERENCE
Ogata K. Modern Control Engineering. 2010
Anonymous. User_s Manual Process Control Technology

EQUIPMENT REQUIRED
1 set Process Rig
1 set Control Module
1 set PC

PRE-EXPERIMENT TASK
1. Explain about PID control and give characteristic of K_p τ_i, and τ_d !
2. Explain about Control System Block Diagram and give two example!

INTRODUCTION
Process control is a branch of control engineering relating to the operation of the plant in an industries such as petrochemicals, foodstuffs, steel, glass, paper, energy, etc. The main objective is to maintain the stability of all variables in the process. Temperature, level, flow, and pressure are the four most common process variables. These four variables are key to process control because it provides a critical condition for boiling, chemical reaction, distillation, extrusion, vacuuming, and air conditioning. Bad control of this four variables can cause safety, quality, and productivity problems. Therefore, it is highly desirable to keep under control and maintained within its safety limits. Process Control Technology PCT-100 is an instrument used to demonstrate various aspects of process control. This equipment facilitate the process control via computer or Programmable Logic Controller (PLC). The main elements of the PCT-100 are the process rig and control module.

Process Rig
Process rig is the main elements of PCT-100 for a diagram of the PCT- 100 can be shown in Figure 1. PCT-100 includes the following elements:

1. Process tank
2. Sump tank
3. Cooler Unit
4. Sump tank Temperature sensor (PRT)
5. Variable speed pump with filter

12. Pressure relief valve
13. Heater
14. Level sensor
15. Pressure transducer
16. Float switch

6. 3/2 Diverter valve
7. 2/2 Proportional control valve
8. Flow rate sensor
9. One way check valve
10. 2/2 Proportional drain valve
11. Needle valve
17. Overvlow
18. Digital LCD displays
19. Indicator Light

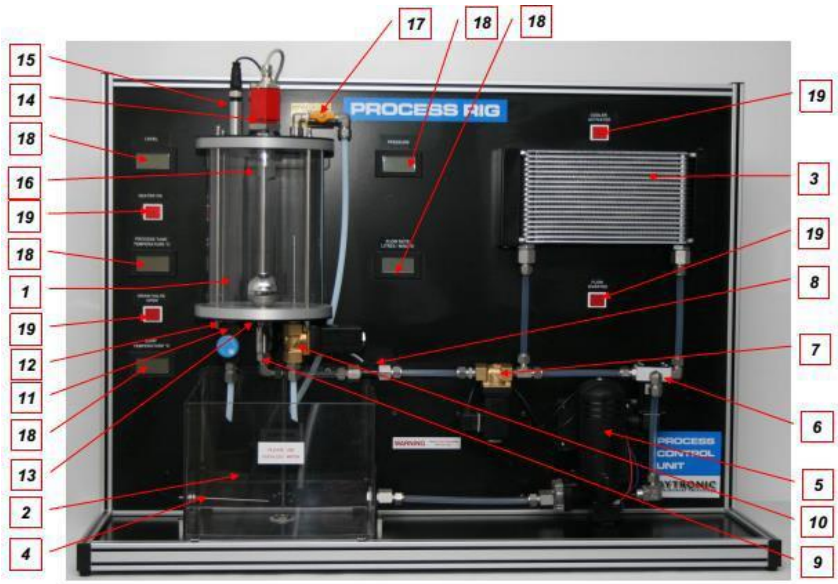

Figure 1. Process Rig of PCT-100

The sump contains a store of distilled water which may be pumped around the system at flow-rates up to about 3.2 liters/minute. Water may be pumped directly from the sump tank to the process tank or be diverted via the cooler. The fluid in the process tank may be drained via the manual or computer controlled valves below the tank, so completing the fluid cycle. The five digital displays are used to show the sump tank and process tank temperatures, flow-rate, pressure and level and the indicator lamps reveal the on/off status of the cooler fan, and computer controlled drain and diverter valves and the heater.

Control Module

The control module incorporates all of the electronic circuitry required to link the process rig to the controller. The design of the circuits demonstrates the interfacing principles required in many process control situations where a mix of analogue, digital and frequency signals have to be processed. Shown in Figure 2, the front of the Control Module has a schematic of the Process Rig, On/Off indicator, six illuminated fault switches, test points, indicators to show the operational status of the elements on the rig, and a backlight switch to turn on the backlights for the displays on the rig.

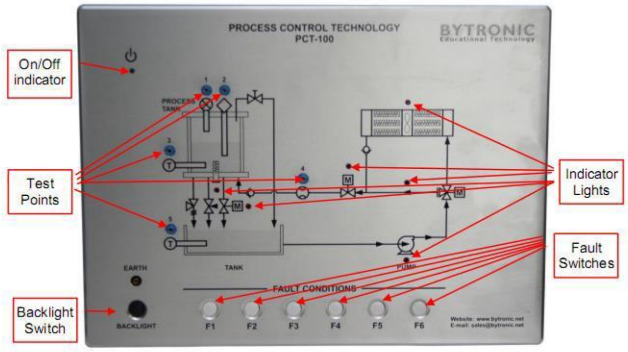

Figure 2. Front part of Control Module of PCT-100

All connections to the process rig and power supply unit are made at the rear of the control module. The USB port on the PC is connected to the USB sockets on the control module and there are analog and digital I/O that is connected to the Process Rig as shown in Figure 3.

Figure 3. Rear part of Control Module of PCT-100

Heater Control

Since the heating element is capable of heating the water in the process tank to a high temperature or causing damage to the tank, several safety features have been incorporated into the PCT-100 system. The safety requirements are as follows:

- The heating element must only be energized when the water level in the process tank is at the required level.
- If any connection between the computer and control module fails or the computer crashes", the heating element must be switched off automatically.
- Tank full signal. The software supplied incorporates an interlock to prevent power being applied to the heater until the signal from the level sensor shows that the process tank is the required level. If students are to write their own control software it is crucially important that they duplicate this software interlock in their program, before they use the heating element.
- Failures or crashes. If the computer-to-control module communication fails, the circuitry

on the control module detects this and turns the heating element off.

The heating element contained in the process tank is controlled by the computer using a pulse width modulation (PWM) technique. The required "mark/space ratio" is determined by a software algorithm in the case of computer control. As the mark/space ratio increases the average rate at which electrical energy is dissipated by the heating element increases, increasing the rate at which the water is heated.

Pump Control
The software initially outputs zero and gradually increases the output to whatever value is unnecessary to achieve the required flow rate. A PID algorithm utilizing feedback from the flow-meter re-calculates the output value at each sample interval.

Switched Faults
With the understanding of how systems operate within industrial control systems there is a great need for individuals with fault finding skills. To help develop these skills, PCT-100 incorporates six individually selectable switched faults located on the front panel of the control module (see Figure 2. Front Part of Control Module). The switched faults are typical of those found in real industrial applications. Generally an electrical fault may be due to one or more of the following:

1. Component failure
2. Electrical short circuit to supply.
3. Electrical short circuit to ground.
4. Crossed signal wires either due to a short or incorrect commissioning.
5. Open circuit due to a broken wire, burnt circuit track or bad connection.

The student may be given fault finding tests following his observation of the correct operation of the PCT-100. The effect of each fault is shown in Table 1. Using standard test equipment in conjunction with circuit diagrams, the faults may be successfully diagnosed.

FAULT NO.	FUNCTION	EFFECT
F1	A/D Fault	ADC LOCKS UP
F2	Pump	PUMP CANNOT BE ACTIVATED
F3	Temperature	PROCESS TEMPERATURE DISPLAYS FULL SCALE READING PERMANENTLY
F4	Cooler	COOLER PERMANENTLY ON
F5	Heater	HEAT DISPLAY GIVES A FAULTY READING
F6	Flow-meter	NO FLOW FEEDBACK

Figure 4. List of switched faults

Flow Measurement
The flow-rate of the water is measured by a turbine type flow-meter. The water flows through the meter and rotates an impeller. Mounted on either side of the impeller is an infra-red transmitter and receiver. The infra-red beam is repeatedly broken by the rotating impellor. The flow-meter produces a pulse train output the frequency of which is proportional to the flow-rate. The approximate full scale output frequency of the flow-meter is 350Hz (pulses/sec). The flow-meter

signal is converted to an analogue voltage by the signal conditioning circuit in the control module. This voltage is used to drive the digital flow-rate display on the rig and converted to digital form

by an ADC for input to the controller. This is all shown diagrammatically in Figure 3.

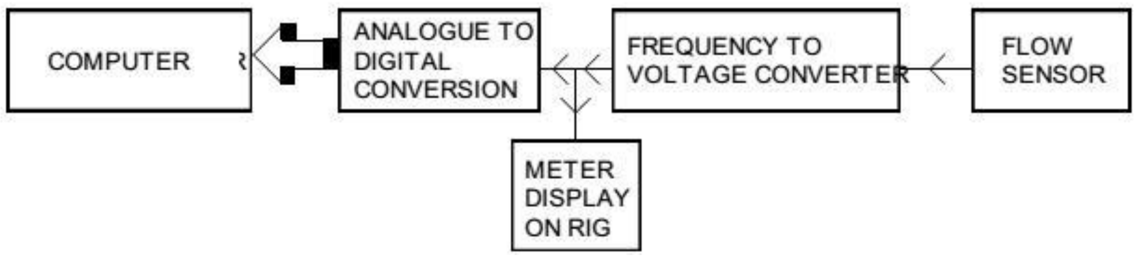

Figure 3. Flow Measurement Diagram

EXPERIMENT

Experiment 1. Proportional Control

These trials generally aims to know the functions and principle of proportional controller on a system. With SP (Set Point) that fixed, steady state value will rise as PG (Proportional Gain) raised. However, there is no value that would be appropriate that PG steady state value will be equal to SP because the proportional control will always produce an error on the controller output. If PG is increased, the magnitude and duration of the oscillations will go up and if PG is too high, the system will undergo some oscillations or will never reach steady state.

A. Operational Procedure

Effect of Changing PG.

1. Set the SP value of flow by 2.0 L/min.
2. Set PG value by 0.5
3. Change the value of PG between 0.5 and 10.0 in accordance with the Table 1 below and write the steady state value in Table 1. Record the response.

Effect of Changing SP.

1. Set the SP value of flow by 0.6 L/min.
2. Set PG value by 1.0.
3. Change the value of SP between 0.6 and 3.4 in accordance with the Table 1 below and write the steady state value in Table 1. Record the response.

B. Experimental Data

Steady state value each changing PG and SP can be write in Table 1. Draw the response from data in step 3 changing PG and SP.

Table 1. Experimental data of proportional control

SP (l/min)	PG	Steady State	SP (l/min)	PG	Steady State
2.0	0.5		0.6	1.0	
2.0	1.0		1.0	1.0	
2.0	1.5		1.4	1.0	
2.0	2.0		1.8	1.0	
2.0	4.0		2.2	1.0	
2.0	6.0		2.6	1.0	
2.0	8.0		3.0	1.0	
2.0	10.0		3.4	1.0	

C. Analysis and Experiment Task

1. What is the effect increasing and decreasing PG value? (prove it)
2. What conclusions about the nature of proportional controller may be drawn from your observations?
3. What is the characteristic P controller?
4. Design proportional controller and calculate the value of error steady state to the system above, by design specification $\tau^* = \tau \times ([3\ last\ digits\ NRP])$. Given K= [3 last digits NRP]/100, τ= [3 last digits NRP].

$$\frac{K}{\tau s + 1}$$

Experiment 2. Proportional + Integral Control

Integral controllers are often used to eliminate the offset caused by proportional control. Short setting controller Integral Action Time (IAT) resulting integral effect greater action on the controller output. Correction is performed on the output by the integral action relating to the PG setting. PG great value means a major correction on the output due to the integral action. Integral Action Time (IAT) is defined as the time taken for the integral action to duplicate the proportional action of the controller, if the error were to remain constant during the period.

A. Operational Procedure

Effect of changing Integral Element.

1. Start a flow loop experiment using only proportional control initially with PG value 1.0.
2. After about ten seconds, add integral element between 999 and 0.1 in accordance with the Table 2 below without changing SP and PG value. Record the response
3. Write the steady state value and your observation of the respond in Table 2.

B. Experimental Data

Steady state value and your observation of the respond each changing parameter I can be write in Table 1. Draw the response in MATLAB.

Table 2. Experimental data of proportional and integral control

SP (l/min)	PG	I	Steady State	Observations
2.0	1.0	999		
2.0	1.0	100		
2.0	1.0	50		
2.0	1.0	10		
2.0	1.0	3		
2.0	1.0	1		
2.0	1.0	0.5		
2.0	1.0	0.2		
2.0	1.0	0.1		

C. Analysis and Experiment Task

1. What is the effect increasing and decreasing Integral value? (prove it)
2. What conclusions about the nature of PI Controller may be drawn from your observations?
3. What is the characteristic PI controller?
4. Design PI controller to the system above, by design specification zero offset and $\tau^* = \tau \times$ ([3 last digits NRP]/10). Given K = [3 last digits NRP]/100, $\tau =$ [3 last digits NRP].

$$\frac{K}{\tau s + 1}$$

4.4.1. Experiment 3. Proportional + Integral + Derivative Control

PID controller is the combination of the proportional, integral and derivative controller. The characteristics of P controller and I have been explained in the previous section. Derivative controller cannot reduce the offset from the set point generated by proportional controller. The correction is performed on the controller output when the process variable changes. Faster the process variables change, the greater the amount of correction by the controller derivative action time (DAT). A little derivative action time means little effect on the output of the controller, so the correction is done at a faster output. The amount of correction performed on the controller output by the derivative action time is affected by the proportional gain setting. The greater the proportional gain, the greater the correction is happening. Derivative control is never used alone because no output controller changes.

A. Operational Procedure

Effect of changing derivative element.

1. Start PCT-100 with SP = 1, PG = 1, I and D is non-active.
2. After a few seconds, set I = 0.35. Record and draw the system responses.
3. Set the value of I become 1. Record and draw the system responses.
4. Start PCT-100 with the same initial condition (SP = 1, PG = 1, I and D is non-active)
5. After a few second, set I = 0.35 and D = 1. Record and draw the system responses.
6. Do the same experiment, but the value of the D = 1.9. Record and draw the system responses.

B. Experimental Data

Draw the system response data (Step 2, 3, 5, and 6) in MATLAB

C. Analysis and Experiment Task

1. What is the effect increasing and decreasing Derivative value? (prove it)
2. What conclusions about the nature of PID Controller may be drawn from your observations?
3. What is the characteristic PID controller?
4. Design PID controller to the system above, by design specification $\tau^* = \tau \times$ ([3 digits NRP]/10). Given K = [3 last digits NRP]/10, A = [3 last digits NRP]/100, B = [3 last digits NRP].

$$\frac{K}{A + Bs + 1}$$

Ziegler/Nichols Tuning

Ziegler Nichols tuning is a semi-empirical method of controller tuning that gives a reasonable guide to the parameters PG, IAT and DAT. Once the values have been determined it might be necessary to apply some fine tuning for optimum performance but in general, Ziegler Nicholls tuning gives acceptable results for many systems. In some cases, integral and derivative control action is reduced to zero and the proportional gain (PG) is gradually increased until a permanent oscillation. At this point the gain (Kp), and the period of oscillation (T) are recorded.

Closed Loop Method

There are two techniques the first called the continuous cycling method assumes that the closed loop system can be made to oscillate permanently with a proportional only controller, as illustrated by Figure 8. The continuous cycling method requires that the gain of a proportional only is increased a small amount at a time until the onset of permanent oscillations occurs. At this point the value of the gain (Kp) together with the period of the resultant oscillation (T) are noted. then given by:

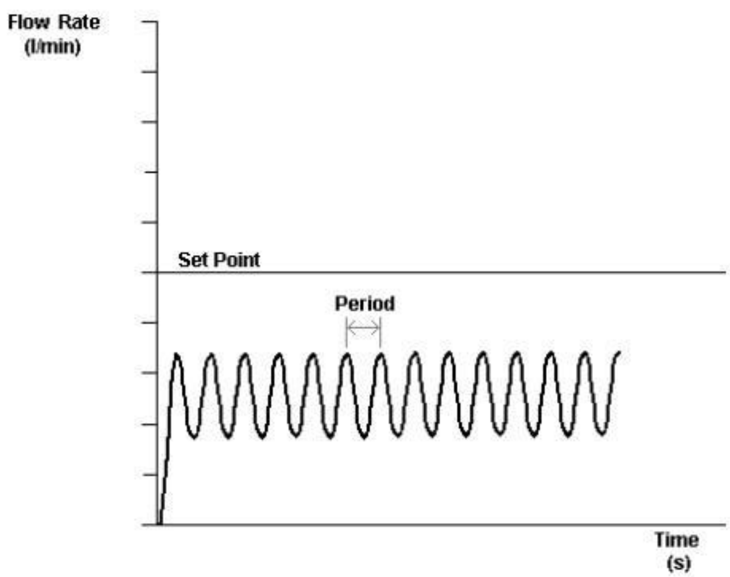

Figure 8. Closed loop flow control system response

Table 3. Tuning PID with Ziegler Nichols

	PG	IAT	DAT
PI	0.45 Kp	0.83 T	
PID	0.6 Kp	0.5 T	0.125 T

A. Operational Procedure

1. Start PCT-100 same as the experiment 1 with SP = 2. Raise the PG value from 1 to 3.5.
2. Try to estimate the value of the lowest PG produces a permanent oscillation on the response.
3. Note the Kp value (gain) and the period of oscillation then use recommendation for PI and PID above
4. After obtained parameters PI and PID controllers, write in Table 4 and apply to the process control PCT-100. Record response results.

Table 4. Tuning PID with Ziegler Nichols

	PG	IAT	DAT
PI			
PID			

Open Loop Method

The second Ziegler/Nichols tuning technique called the, process reaction curve method" requires that an open loop step response curve is produced showing a measurable, transport delay'' or, dead time''. (Transport delay is the period during which there is no change in the process variable after the controller output has been stepped or down). The following graph shows a typical process reaction curve in Figure 9. The process reaction curve method requires that an open loop step response of the system is obtained as shown above. From this graph the maximum slope (R) and the transport delay (L) are noted. The step input expressed as a fraction of the total range of the input (Δu) is also required. (In the open loop section of the PCT-100 software the step input fraction Δu is calculated very easily since the step input to the pump is specified as a percentage

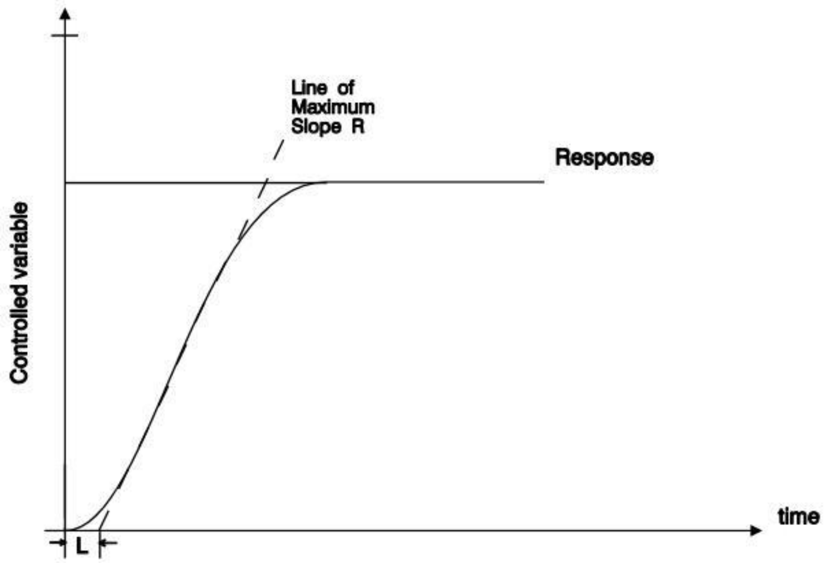

Figure 9. Process reaction curve

Table 5. Tuning PID with Ziegler Nichols

	PG	IAT	DAT
P	$\frac{\Delta u}{RL}$		
PI	$0.9\ \frac{\Delta u}{RL}$	$3.3\ L$	
PID	$1.2\ \frac{\Delta u}{RL}$	$2\ L$	0.5 L

A. Operational Procedure

1. Start PCT-100 and select open loop option from main menu
2. Run open loop simulation with step response input pump 80%
3. Try to estimate the value of the R, L and _u from graph
4. After obtained parameters PI and PID controllers, write in Table 6 and apply to the process control PCT-100. Record response results.

B. Experimental Data

Draw the response in MATLAB. Fill Table 6 with the parameter P, PI and PID that you obtained.

Table 6. Tuning PID with Ziegler Nichols

	PG	IAT	DAT
P			
PI			
PID			

C. Analysis and Experiment Task

1. Compare with analytical method in PI (Experiment 2) and PID (Experiment 3) with Ziegler Nicholls Tuning
2. Compare Ziegler Nicholls between open loop method and closed loop method.