PITOPS PID HOMEWORK LAB EXERCISES

CONTENTS

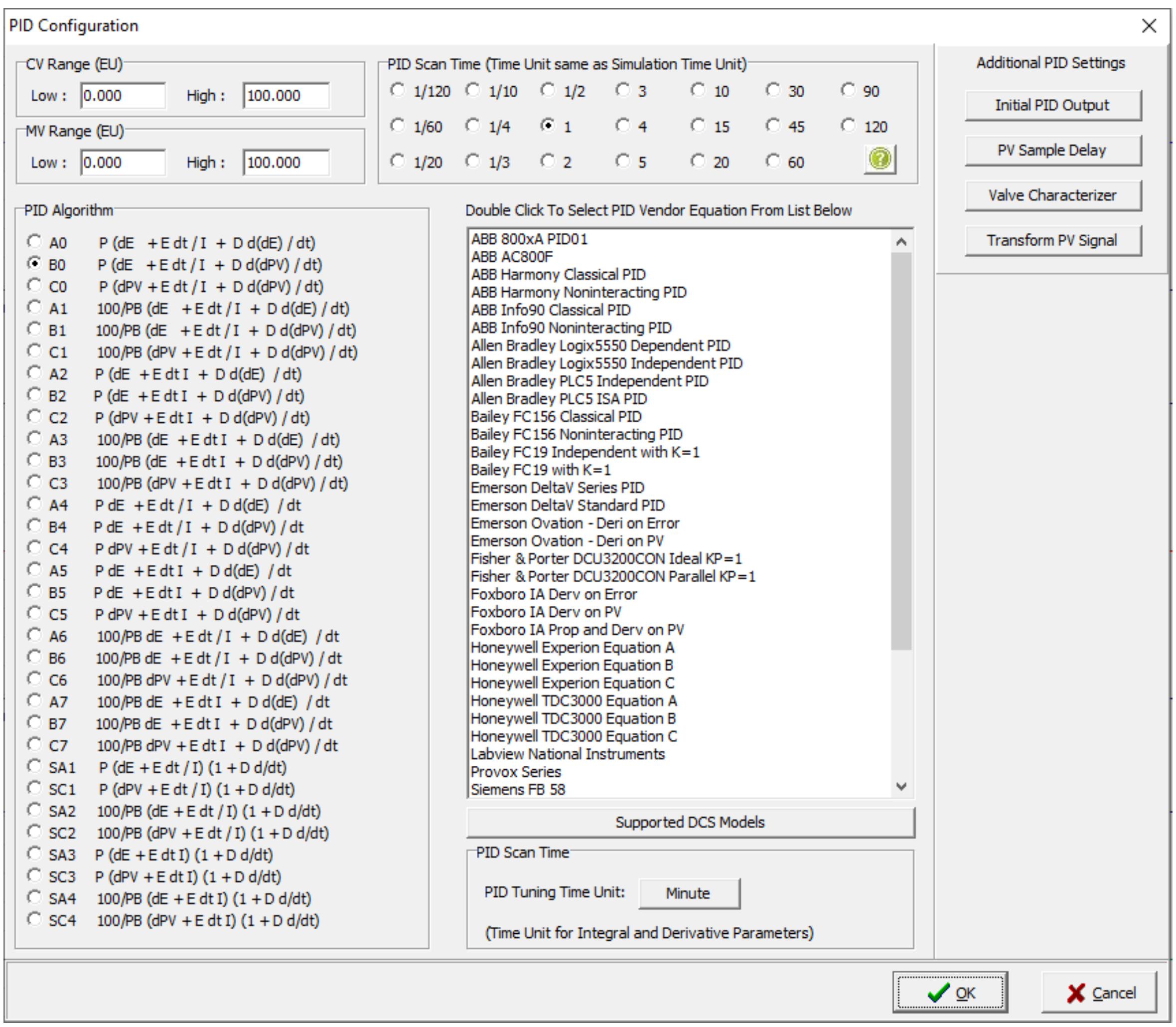
PART B: **EXAMPLES ON PID TUNING & ADVANCED CONTROL**

1.0 INTRODUCTION

This part helps the user to get started on how to tune PIDs using PITOPS-PID. Illustrative examples are provided for tuning FC, TC, LC and cascade PID. Examples are provided also on feedforward and model-based controller strategies. Each example consists of detailed step-by-step procedure on how to configure PITOPS.

After starting PITOPS, the first step is to identify transfer functions using the System Identification tab located near the top left corner of the screen.

After identifying transfer functions, the next step is to click the PID/APC Optimization tab also located near the top left corner of the screen. This document covers all aspects of the PID Tuning and APC design and optimization functionality. The ***very first time*** when the PID/APC Optimization tab is clicked after identifying transfer functions, the following screen pops up:



This window allows you to configure the PID controller details. Here, you can specify the PID Scan Time, PID Tuning Time Unit, PID Equation, CV Range, MV Range and other additional less frequently changed advanced parameters. All parameters and their functionalities are explained later in this manual.

Pull-down menu bars are located near the top left section of the screen and are labeled as: **| File | Run | Help |**. Click on the pull-down menus to see the pull-down menu options.

Under the pull-down menu bar is located the icon tool bar. Everything from the pull-down menus can be also conveniently accessed using the icon tool bar. The icon tool bar labels are shown below. You can locate the cursor on each icon to see its labeled description.

The shapes and appearance of all various icons, their labels (what they stand for) is shown below.

1) 2) 3) 4) 5) 6) 7) 8) 9) 10) 11) 12) 13)

1) New Case File
2) Open Case File
3) Save Case File
4) Print
5) Add/Edit Case Files Notes
6) Help
7) Simulate
8) Single/Slave PID Configuration
9) Master PID Configuration
10) PV Signal Noise
11) PID Tuning Criteria / Optimization
12) Robustness Analysis
13) Map Data Entry

The examples below are designed to help you quickly start using the PITOPS-PID program and put it to practical use.

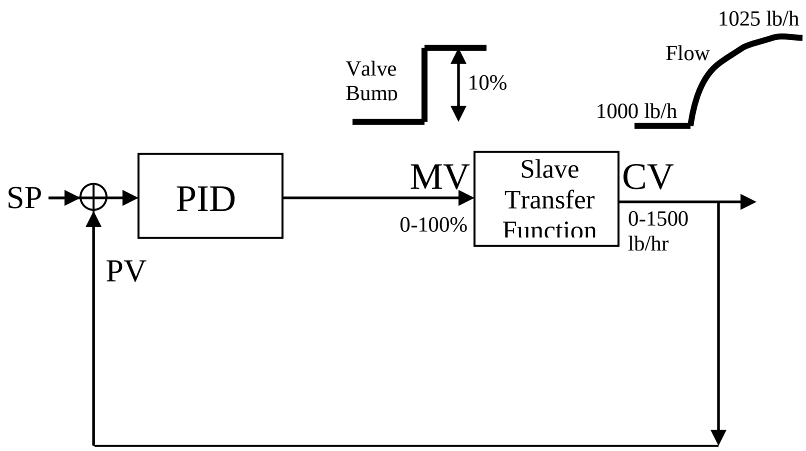
Detailed explanation on each of the icons, tool-bar options and all user-entered screen fields are explained in Part C.

Now continue to section 2 below – Configure a Transfer Function.

2.0 CONFIGURE A TRANSFER FUNCTION

This section helps the user to configure a transfer function and watch its open loop response. A typical flow PID (FC) is used for study. The FC is in manual mode. Make 10% change in the PID output (valve position). Initial value of flow is 1000 lb/h. After a dead time of 30 seconds, flow rises to 1025 lb/h. Time constant is 40 seconds. The FC flowmeter range is 0-1500 lb/h. See Figure 1 below:

Figure 1. Transfer Function Configuration



The procedure to configure a transfer function is given below:

1. Start PITOPS-PID software by double-clicking on the PITOPS icon. Click on PID/APC Optimization tab located near the top left corner of the main window. Click OK when you see the PID Configuration screen. You can access this screen also by clicking on PID Configuration icon (located on the icon tool bar near top of screen).

2. Click on the icon New Case File. Click Yes in response to the pop-up message. This clears all data from a previous PITOPS run, initializes all variables to some default values and prepares for a new PITOPS run. This is recommended before the start of every new PITOPS run.

3. Under the Process Transfer Function area on the right side of the screen, if you select TF1, then the transfer function parameters are automatically populated from the Transfer Function #1 values from the transfer function identification – click on System Identification near the top left corner of the screen and see the values under Transfer Function #1. Now click on PID/APC Optimization near the top left corner of the screen and if you select TF1 under Process Transfer Function, then you will see this automatic transfer from Transfer Function #1 under System Identification to the transfer function parameters under Process Transfer Function. If under System Identification, there are transfer functions #2 and #3, then under PID/APC Optimization, you will see options TF1, TF2, TF3 and User under the Process Transfer Function area. Only the User option allows the manual entry of transfer function parameters. Selecting TF1, TF2, or TF3 results in automatic populating of the transfer function parameters from the System Identification window. Note that the unit of Sample Time (millisecond, second or minute) under System Identification window is also automatically pulled and set to the units of Simulation Time and Process Transfer Function

Parameters under PID/APC Optimization. So, if you need to change the units of Simulation Time and Transfer Function Parameters under PID/APC Optimization, then click on Millisecond, Second or Minute next to Simulation Time and select appropriately.

4. Under the Process Transfer Function area on right hand side of the screen, click on the down arrow to the right of Transfer Function From and select User. When this selection is User then you can manually set the transfer function parameters. Set Delay = 30, Gain = 2.5 (thus is the transfer function process gain and not the PID controller proportional gain), Tau1 = 40. Note that the transfer function process gain is calculated as (1025 -1000 lb/h) / 10% (see Figure 1 showing the valve bump and the change in flow).

5. Click on PID Configuration icon (located on the icon tool bar near top of screen) and then set CV Range (EU) High = 1500 (lb/hr) and CV Range (EU) Low = 0. MV Range (EU) High = 100% and MV Range (EU) Low = 0% represents valve range; leave them unchanged.

   The PID equation can be selected here. We will use PID equation B0 in this example. To select the PID Equation, click on any of the options in the PID Equation table. You can also select the PID Equation by double-clicking on the DCS/PLC name and model under the box labelled "PID Vendor Equation List ". If your DCS/PLC vendor or model is not listed here or if you are unsure about your PID Equation and do not have access to your DCS/PLC manual, contact PiControl for assistance on selecting the correct PID Equation. For seeing the list of all PID equations supported in PITOPS on all the various DCS/PLC vendors and models, click on the box labelled "Supported DCS Models". If your DCS/PLC vendor or model is not listed, contact PiControl for requesting addition of your vendor and model into the PID Equation menu.

   Notice that the PID Tuning Time Unit is Minute. Click on Minute and select Second. This means that the integral and derivative parameters for our DCS are in seconds. If the DCS PID tuning time unit is minutes, then the integral and derivative constants must be specified in minutes. To change the time unit, click on Second and change the selection to Minute in the PID Time Unit box. For this example, we will use Second as the PID time unit, so keep the selection as Second. Click OK to close the PID Configuration window. PITOPS provides complete flexibility regarding the PID equation and time unit. You can manually choose the PID equation and the PID Tuning Time Unit in addition to the DCS/PLC vendor equation options.

6. Under Tuning, set P = 0. Proportional Gain is set to zero (no PID action); PID is now in Manual mode.

7. On the right side of the screen, set both SP Old and SP New = 1000 (lb/hr). This means, our process was at 1000 lb/hr at the start time of the simulation.

8. Also, on right side of the screen, set Valve Bump = 10 (%). This means that at time = 0 (start time), we bump the valve up by 10%.

9. Near the top of the screen, set Simulation Time = 200. This means we want to see the simulation for 200 time units. To the right of the Simulation Time, notice that "Minute" is displayed. Click on Minute. You will see three options – Millisecond, Second and Minute. This option denotes the time unit for the simulation and all the transfer function parameters.

Select Second. Now our simulation time unit is set to be in seconds. Since we specified the Simulation Time = 200, this means we are simulating for 200 seconds.

All transfer function parameters (Delay, Tau1 and Tau2) should be specified in the same time unit as the Simulation Time. Thus, the Delay we specified above is 30 seconds and Tau1 (first order time constant) is 40 seconds.

Note that in step #4 above, we specified the DCS time unit for the integral and derivative tuning parameters. Here, in this step, we specify the simulation time unit which specified the time unit for the simulation time (X axis) and the transfer function parameters.

Thus, for very fast loops like compressor surge control, the simulation time unit can be set to Millisecond and the PID time unit can be set to Minute in step #4 above. In this case, all transfer function parameters must be specified in milliseconds, the simulation time will be also in millisecond, but the integral and derivative tuning parameters should be specified in minutes.

Various DCSs use seconds or minutes for the integral and derivative tuning constant time unit. Thus, PITOPS provides complete flexibility in handling very fast to very slow process dynamics while displaying the integral and derivative tuning parameters in the correct (compatible) DCS time unit.

10. Click on the Simulate icon. The ***top window*** shows the PID PV (red) and SP (blue). The ***middle window*** shows PID OP (output).

    See the transfer function response. At time = 0 (start time of simulation), the valve position is increased from 50 to 60%. After a 30 second delay, the flow starts rising from 1000 lb/hr. Notice that 40 seconds are required to reach 63% of the total change from 1000 to 1025 lb/hr (1016). The above curve is called the open loop response. Examine the plot and check the transfer function parameters based on the shape of the curve.

11. **Zoom** and **Drag** feature: Inside any plot window, click with ***LEFT mouse button*** on top left corner of the area to be zoomed. Keeping the button pressed, move the mouse to specify the bottom right corner of the area to be zoomed. A rectangle marks the selected area. Release the left mouse button. The section is zoomed.

    Double click to **restore** the full original plot after zooming.

    Locate cursor arrow anywhere on the plot and press the ***RIGHT mouse button***. Move the mouse up, down, right or left. The entire plot can be scrolled. This feature works also on a zoomed section.

    Double click to **restore** the original plot after scrolling.

12. Notice that PID OP (valve position) was 50% at time = 0 and after the 10% bump increases to 60%. The 50% initial position is a default parameter and rarely needs to be changed. If you want to change this value, click on the PID Configuration icon (located on the icon tool bar near top of screen) and type in a new value for Initial PID Output.

13. On right side of the screen, type in different transfer function parameters and study the

different open loop responses. Click on the Simulate icon after making any data changes to see the new simulation.

14. To study a second order response, type in Tau2 = 5 (keeping other parameters the same). Click Simulate. Notice the second order wavy transfer function shape.

15. The PV and OP trends can be exported to an Excel data file. Click on File and then click on Generate Vector Files. Specify a filename in which to export the screen trends.

    Inside the Excel file, the first column contains time of file creation. The time samples are all constant. This first column containing time stamps is not useful as is but is created to keep the file structure the same as the files used by the PITOPS-TFI module that identifies transfer functions using plant data files.

    The second column is labeled CV (Controlled Variable) and contains the PV (Process Variable) data.

    The third column is labeled MV1 (Manipulated Variable #1) and contains the PID Raw Output data.

    The fourth column is labeled MV2 (Manipulated Variable #2) and contains the Disturbance PV data.

    The Excel file consists of a three-line header at the top followed by 200 data points (Simulation Time specified in Step 8 was 200), at unit time sample intervals. The number of data points can be changed by changing the simulation time. The three-line header at the top can be changed to add more or less lines (rows); refer to the procedure explained in Part C, Section 13.4.

    The Excel file generation feature can be used to improve model predictions in MPC (Model Predictive Control) systems. First, the user will identify transfer functions using the System Identification module and then generate an Excel file using the procedure described in this section.

15. Click on the icon labeled (Map Data Entry) located in the top-bar. This shows a process control schematic showing the various control functions programmed in PITOPS-PID software. All parameters described earlier in this section- Slave Transfer Function Parameters and Slave PID tuning parameters can be entered from this screen also.

16. In the top toolbar, click on the icon labeled Add / Edit Case File Notes. A new window called “Notes” pops up. You can enter comments, thoughts and notes related to this case file in this window. To save your comments click on the “Save” box near the bottom of the popup window. These comments are saved as part of the case file. When case files are restored later, these comments are viewable.

    The complete simulation can be restored with the case file Ex1.pid (supplied with PITOPS-PID software). To restore the case file, click on the Open Case File icon, navigate to the desired subdirectory where PITOPS software was installed and then select the file Ex1.pid and click on Open to complete reading the file data.

3.0 TUNE A PID WITH A SETPOINT CHANGE

In this section, we will configure a PID (FC) and then simulate a Setpoint (SP) change with various PID tuning parameters. PITOPS-PID will determine optimum tuning parameters using the IAE (**I**ntegral **A**bsolute **E**rror) criterion. You can try different sets of PID tuning parameters and see their effect in the PITOPS simulation.

1. Continue from the example in Section 2 above. Make sure that Delay = 30, Gain = 2.5, Tau1 = 40, Tau2 = 0.

   Remember that (as explained in the above example in Section 2) the **transfer function parameters** and **time axis** are in **seconds** and the **integral** and **derivative** tuning constants are also in **seconds**.

2. The Integral and Derivative tuning constants in a DCS or PLC can have the units of either minutes or seconds (or reciprocal minutes or reciprocal seconds). Let us change the DCS tuning parameter time unit to minutes. To do this, click on the PID Configuration icon and inside the PID Configuration pop-up window, you will see PID Time Unit. Click on the box labelled Minute or Second and select Minute. Now our Integral and Derivative time tuning parameters will be in minutes.

   Change Valve Bump to 0.0 (now we wish to observe the PID action on the valve; the valve bump is used only to see open loop response, never when PID is active).

3. Change SP New to 1030 lb/hr. SP Old should be 1000. We wish to simulate a setpoint change from 1000 to 1030 with the PID in automatic mode.

4. Under PID Tuning Parameters, set P = 0.5, set I = 0.25 (minutes). Note that the Integral tuning parameter is in minutes but the simulation time unit here is seconds (this is because near the top of the screen, Simulation Time = 200 Seconds). The unit of Simulation Time near top of the screen applies to all time-dependent parameters (Delay, Time Constants-Tau1, Tau2 and Simulation Time) but the PID Time Unit (seen after clicking on the PID Configuration icon) applies to the Integral and Derivative tuning parameters only.

5. Near the top of the screen, change Simulation Time to 500 (seconds). We wish to watch the PID control action for 500 seconds after the setpoint change from 1000 to 1030 lb/hr.

6. Click on the Simulate icon in the top-bar. Examine the plot.

   The ***top window*** shows the SP and PV trends. The blue trend in the top window shows the setpoint change. The red trend in top window shows the actual change in flow (flow PV).

   The ***middle window*** shows the PID Output (OP) going to the control valve. The PID output manipulates the valve to achieve the flow change.

   The ***bottom window*** shows the individual P (Proportional), I (Integral) and D (Derivative) contributions. The sum of these three contributions comprises the total PID controller's control action. Note that if you do not see "PID Contribution" in the bottom window, then click on the button labeled "PID Contrib" near the bottom right corner of the screen. This button toggles from displaying PID Contribution and PID Raw Output.

Note the Error value shown on the right corner of screen. This value is the integrated error between PV and SP calculated over the simulation time. The default error criterion is the IAE (Integral Absolute Error).

7. The PID control action appears rather slow (sluggish). Let's try more aggressive tuning. Change P from 0.5 to 1.0. Click Simulate. A small **overshoot** can be seen now for the PV response.

8. Click on the PID Tuning Criteria / Optimization icon and click on PITOPS-IAE to run the optimizer. The PITOPS optimizer determines new tuning parameters (this may take several seconds). Notice that now the Proportional Gain (P) is changed to around 5.5 and the Integral (I) is changed to about 0.8 minutes.

   The PITOPS optimizer determines new and improved tuning parameters based on the selected error criterion. This example uses the IAE criterion. Several other PID tuning options are provided and can be seen by clicking on the PID Tuning Criteria / Optimization icon. You will see the four PITOPS options – IAE, ISE, ITAE, RO and various other criteria (these are all explained in detail in Section C).

   Click on the PID Tuning Criteria / Optimization icon to see the various PID tuning options. The IMC (Internal Model Control) criteria produce medium-fast tuning and control action. ZNOL (Ziegler Nichols) and CC (Cohen Coon) are very aggressive but can be slowed down by entering Prop Gain Adjust value to be less than 1.0. Lambda tuning is generally slow but can be made faster up by setting the Lambda Factor at its lowest limit of 1.0. Generally, the PITOPS-IAE and PITOPS-ISE criteria produce rather aggressive control action. The PITOPS-ITAE criteria is somewhat slower than PITOPS-IAE and ISE. Use the PITOPS-RO error criterion for generating less aggressive and more practical tuning parameters, suitable for use in the real plant.

   In the PID Tuning Parameters box, if D (Derivative is zero), optimizer will keep D at zero (a new value will not be calculated).

9. Note the value of current OP ROC (Rate of Change) located near the bottom right corner of the screen. The Max. OP ROC is the maximum allowed change in the PID output during two consecutive PID executions (scan times). Excessive valve changes may be undesirable in a given process. The OP ROC is a measure of how fast the valve is moved by the PID control action. Based on process knowledge, user can reduce that valve movement if it is excessive. PID tuning parameters then may be modified to reduce the OP ROC.

   Notice the large change in PID OP at time = 0. This is called the **Proportional Kick** and is entirely due to the proportional contribution. Higher the P, larger will be the proportional kick. Notice that the ROC value is equal to the proportional kick as seen from the plot.

10. Is the proportional kick too large here? It depends on the process characteristics. Let’s say, based on our process knowledge, we want to limit the current ROC to 4. Change the Max. OP ROC from 100 to 4. In this case, we do not want the PID OP to change by more than 4% during any two consecutive cycles.

Click on the PID Tuning Criteria / Optimization icon and click on PITOPS-IAE to search for new optimal PID values corresponding to the IAE criteria subject to the 4% Max. ROC limit. The optimizer calculations may take a few seconds to about a minute to complete and during which time you will see the blue bar scrolling near the bottom of the screen informing that calculations are in progress. After completion of optimizer, note that now Current OP ROC = Max. OP ROC = 4.0. The new tuning parameters are: P about 6 and I about 0.7 minutes. Notice that these parameters are now different. PITOPS optimizer has minimized the IAE by computing new P and I tuning parameters while satisfying the OP ROC constraint limit whereby the OP can move no more than 4% between two consecutive scans. Note also that in the middle plot, near time = 0, the PID OP jumps from 50% to about 54%. This difference (54 – 50 = 4) is the Current OP ROC of 4.0. The PITOPS-PID optimizer thus satisfied the 4% Max. OP ROC constraint while determining the optimum PI tuning parameters.

11. Try different PI values to see if you can further minimize the Error value. Try Derivative from 0-3 and watch the effect on the setpoint change.

12. PITOPS-PID software also provides popular tuning options. Click on PID Tuning Criteria / Optimization icon located in the top-bar. You will see the following available selections:

a) **Help**: click to obtain help on how to use these PID tuning criteria.
b) **IMC-PI**: Select this option to calculate PI (proportional and integral tuning parameters) based on the IMC (Internal Model Control) tuning criteria.
c) **IMC-PID**: Select this option to calculate PID (proportional, integral and derivative tuning parameters) based on the IMC (Internal Model Control) tuning criteria.
d) **ZNOL-P**: Select this option to calculate P (proportional-only tuning parameter) based on the Ziegler-Nichols Open-Loop tuning criteria.
e) **ZNOL-PI**: Select this option to calculate PI (proportional and integral tuning parameters) based on the Ziegler-Nichols Open-Loop tuning criteria.
f) **ZNOL-PID**: Select this option to calculate PID (proportional, integral and derivative tuning parameters) based on the Ziegler-Nichols Open-Loop tuning criteria.
g) The **Prop Gain Adjust** is to detune the ZNOL proportional gain. The default value of Prop Gain Adjust is 1 and this may produce oscillatory control action using ZNOL criteria. Reduce the value to (say) 0.7 or 0.5 to produce less aggressive tuning.
h) **CC-P**: Select this option to calculate P (proportional-only tuning parameter) based on the Cohen-Coon tuning criteria.
i) **CC-PI**: Select this option to calculate PI (proportional and integral tuning parameters) based on the Cohen-Coon tuning criteria.
j) **CC-PID**: Select this option to calculate PID (proportional, integral and derivative tuning parameters) based on the Cohen-Coon tuning criteria.
k) The **Prop Gain Adjust** is to detune the CC proportional gain. The default value of Prop Gain Adjust is 1 and this may produce oscillatory control action using CC criteria. Reduce the value to (say) 0.7 or 0.5 to produce less aggressive tuning.
l) **Lambda-PI**: Select this option to calculate PI (proportional and integral tuning parameters) based on the Lambda PI tuning criteria.
m) **Lambda-PID**: Select this option to calculate PID (proportional, integral and derivative tuning parameters) based on the Lambda PID tuning criteria.
n) The **Lambda Factor** is to speed-up the Lambda tuning control action. The default value of Lambda Factor is 2.5 and this may produce slow control action and a new

setpoint change may take too long to reach. Reduce the value to (say) 1.0 to produce the fastest Lambda recommended tuning parameters.

o) **PITOPS-IAE**: Select this option to run the PITOPS optimizer that minimizes the integrated absolute error.

p) **PITOPS-ISE**: Select this option to run the PITOPS optimizer that minimizes the integrated square error.

q) **PITOPS-ITAE**: Select this option to run the PITOPS optimizer that minimizes the integrated time absolute error.

r) **PITOPS-RO**: Select this option to run the PITOPS optimizer that produces stable and crisp control but with reduced proportional kick that may reduce overshoot upon a setpoint change.

If the **ZNOL or CC criteria** produce tuning that is too aggressive or too sluggish for any reason, there is a Proportional Gain Multiplier that can be adjusted to achieve the desired effect. Click on the PID Tuning Criteria / Optimization icon and click on Proportional Gain Adjust. The default value is 1.0. To make the tuning criteria less aggressive, use a value around 0.5 to 0.75 and to make it more aggressive, use 1.2 to 1.5. This value multiplies the Proportional gain calculated by the above criteria.

The **Lambda PI and PID tuning criteria** require the specification of "The Lambda Factor" which can be modified as follows: Click on the PID Tuning Criteria / Optimization icon and click on Lambda Factor. The typical range of values for Lambda Factor are 2.5 to 3 (slow) to 1 (fast/aggressive). Values more than 3 may produce very slow/sluggish tuning.

Note that the PITOPS-IAE error value produced a lower error but moved the valve too quickly. P = 3 and I = 0.5 minutes are more reasonable and practical, both smooth and stable.

13. Under the SP New value, see the SP ROC field. SP ROC stands for Setpoint Rate-of-Change. This allows the Setpoint to be ramped slowly instead of an abrupt step. Change the SP ROC to 0.5. Click Simulate . Notice now the Setpoint is ramped from 1000 to 1030 in 60 seconds. The change in Setpoint is 1030-1000 = 30 EU (Engineering Units) and is made over 60 seconds and 30/60 = 0.5 EU/sec, which is the specified SP ROC value.

14. Click on the More button under the Filter value in the PID Tuning Parameters box. You will see additional parameters related to the PID algorithm. These are Derivative PV Lag, Auto Derivative Filtering ON/OFF, Error Deadband, Gap Gain, Gap Low and Gap Hi. These are all explained in detail in Part C of this manual.

15. Notice the OP Limits (Low Limit and High Limit) fields near the middle, right part of the main screen. These limits place a clamp on the PID's Output. Set Low Limit = 55 and High Limit = 60. Click Simulate . Examine the OP (Output) trend. Notice now that the PID OP is clamped to 55 and 60 (the clamp limits). PID OP clamps are often used in DCS and PLCs for preventing the PID OP from going outside a known safe and recommended operating zone.

16. Now let's say we want to change our PID tuning time unit to Second. This means that the Integral and Derivative tuning constants are in seconds. To make this change, click on PID

Configuration icon, located in the tool bar near the top of the screen. Next to PID Tuning Time Unit click on Minute and select Second. Click OK.

Now you will see large oscillations in the PV and OP. This is because the Integral constant of 0.5 is now in seconds and this is too strong (too strong integral action). Click on the PID Tuning Criteria / Optimization icon and click on PITOPS-IAE to run the optimizer. After a few seconds, when the optimizer has completed its calculations, notice that the Integral (I) changes to about 40 Seconds.

17. PITOPS PID also provides certain other useful advanced functions. To access these, click on PID Configuration icon and then see PV Sample Delay, Valve Characterizer and PV Transform Signal.

PV Sample Delay simulates PV sample hold encountered in GC (gas chromatograph) online analyzers where the PV signal does not change for some specific time typically from 1 to 30 minutes. Change the value to 10 and see the effect on the simulation.

Valve Characterizer allows simulating nonlinear behavior commonly encountered in control valves. Valve characterizer is often low between 0-20% valve position and even lower from 70-100% valve position. The valve characterizer allows setting of 10 multiplication factors covering the entire 0-100% of the valve movement range. Each 10% range can be set with an individual multiplication factor. Typical multipliers for 0-10 and 0-20 will be small- around 0.5 to 0.7. Also, typical multipliers for 70-100 will be in the range of 0.2 to 0.7.

PV Transform Signal allows applying a transform on the raw PV before it is read by the PID in the PID error calculation. Example, if Natural Logarithm is used, then the PID PV is not the raw signal but the natural logarithm of the raw signal.

This complete simulation can be restored by clicking on the Open Case File icon and then selecting Ex2.pid.

4.0 ADD RANDOM NOISE

Random noise is always present in plant signals. Flows are particularly very noisy. We add random noise in this section to make a more realistic simulation. Also, we study derivative action here; this is meaningful only when the right amount of noise level is present in the simulation.

1. Continue from end of Section 3 above. Click on the Open Case File icon and then select Ex2.pid. Notice that under Tuning, P = 3, I = 0.5 (minute). Click on the PV Signal Noise icon. Click Up-Arrow for Single/Slave PV Noise several times until the value is about 0.5. Click OK and click Simulate. Notice now that the flow (CV) looks more realistic with the random superimposed noise.

   The 0.5 value for noise means that the noise band is 0.5% of the instrument range (CV range). The CV range can be seen by clicking on the PID Configuration icon.

2. Inside the PID Tuning Parameters box, set D = 0.5 (Derivative in minutes). Click Simulate. Examine the plots. Notice the large fluctuations in the valve (PID OP), the middle plot. These are caused by the high derivative action and the noise. Try different sets of derivative constants from 0 to 1.0.

   Note: Generally, derivative on FCs is set to zero. In this example, derivative is used for illustrative reasons only. Derivative action is not used for FCs.

3. Set P = 3, I = 0.5 (minute) and D = 0.1 (minute). Click Simulate. Note the Error value and the shape of PV, OP trends.

   Make sure the ROC constraint is disabled (to disable, set Max. OP ROC = 100.

   Click PID Tuning Criteria / Optimization icon and click on PITOPS-IAE. Notice that now a non-zero D (Derivative) value is also calculated. With high noise level for fast loops (as is the case here), derivative is never desired, but the purpose here is to only illustrate the use of the various functions of the PITOPS simulator and optimizer.

   Cancel noise by clicking on Single (Slave) PV Noise, Yes for Cancel All Noise. Click OK.

   Click PID Tuning Criteria / Optimization icon and click on PITOPS-IAE. Try different values for the derivative and click on the Simulate icon to see the results. In the absence of noise and with just a setpoint change, a higher value of D may not appear harmful but for fast loops, the use of derivative action is rare and unnecessary.

   For loops with slow dynamics (long time delay and/or long time constant), the derivative action can add to the stability of the loop, allowing a higher gain (P), provided that the PV signal is not excessively noisy.

   Add different amount of noise again and see the impact of derivative action. This complete simulation can be restored by clicking on the Open Case File icon and then selecting Ex3.pid.

5.0 CONFIGURE EXTERNAL DISTURBANCE

In this section, we configure an external disturbance and then tune the PID to respond well to both a disturbance and a setpoint change. PID tuning should always be determined based on both setpoint change and disturbances. Tuning that is determined for only one case may be too sluggish or unstable in the other case.

The control configuration for the external disturbance is shown in Figure 2.

1. Start a fresh simulation by clicking on the New Case File icon and click Yes.

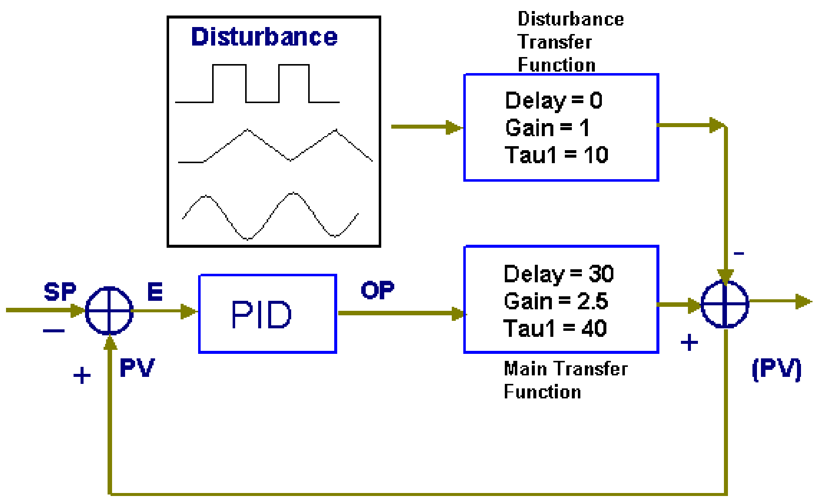
2. Change P = 3.5, I = 40, D = 0. Make sure that Max. OP ROC = 100 and Valve Bump = 0. Under Process Transfer Function on right side of the screen, change Delay = 30, Gain = 2.5 and Tau1 = 40. Change Simulation Time (near top of screen) = 800 and make sure it is in Minutes. The Simulation Time unit (Minutes, in this case) also applies to the Delay and Tau1 which are also in minutes.

3. Click on PID Configuration icon and set CV Range 0 to 1500. Leave the MV Range 0 to 100 (default values). Make sure that the PID Scan Time is 1 and the PID Tuning Time Unit is Minute. Click Simulate .

4. Near the bottom left corner of the screen click on the button Disturbance Transfer Function, and set Gain = 1.0 and Tau1 = 10**.** For disturbance to work correctly, Time Constant must be greater than or equal to 1.0, usually it is set to 10.

5. Now we will add a pulse disturbance. Go to Disturbance Signal box and click ON to activate Pulse. Set Start Time = 300, End Time = 500, Width = 200, and Change = 20. Keep Pulse disturbance to appear as Regular signal. Click on the Random will make Pulse to behave as a random (unexpected) signal.

Figure 2. External Disturbance



6. Now we will add a ramp disturbance. Click on the Ramp disturbance. Click ON to activate Ramp disturbance. Set Start Time = 300, End Time = 1000 and Rate = 0.03 (this is the ramp rate). Set Change = 1000. This means keep ramping in the same direction until the ramp value is 1000. Since 1000 is a high value, the effect is for the ramp signal to increase only in this case. A small value will cause the ramp signal to ramp up and down creating a triangular saw-tooth pattern. Click Simulate

7. Now we will add a sinusoidal disturbance. Go to Sine disturbance. Click ON to activate Sine disturbance. Set Start Time = 300, End Time = 1000 and Frequency = 0.05 (this is in radians/time unit). Set Amplitude = 3 (this is the amplitude of the sine wave). Click Simulate

   The real or simulated pattern of a disturbance can be also entered using the Excel data. Under the Disturbance Signal, in the Sine disturbance box there is a button Insert Disturbance File which allows user to add some other trajectory of a disturbance into PITOPS-PID module. If user clicks on the button Insert Disturbance File, he will need to load desired disturbance Excel file by selecting it, pressing Open and clicking Simulate.

8. Set SP Old = 1000 and set SP New = 1030. Click Simulate . Examine the PV, SP and OP trends. See the configured disturbance signal on the top right window. See the PID control action (changes in OP) in the left middle window as the PID tries to reject the disturbance.

   Note that the disturbance signal is the combined effect of the three components - pulse, ramp and sine. This combined signal is passed through the disturbance transfer function with unit gain and time constant = 10. The disturbance signal is subtracted from the PV. An upward change in the disturbance signal causes a downward change in the PV.

9. Click PID Tuning Criteria / Optimization icon and click on PITOPS-IAE to run the optimizer. The optimizer now will determine the optimum PI parameters corresponding to minimum IAE Error.

10. Now try to use derivative action. Determine optimum PID parameters with the current SP change and disturbance. Set P = 3, I = 30, D = 1. Click Simulate . Note Error. Click PID Tuning Criteria / Optimization icon and click on PITOPS-IAE to run the optimizer. The optimizer now will determine the optimum PID parameters. Notice again that at minimum error, the calculated optimum D is rather high. Good tuning for this case is: P = 4.5, I = 50, D = 2.

    Notice also that use of derivative action allows increasing the Proportional gain. In the real plant, using derivative beyond 2-3 is not desirable because of noise in the signals and restrictions on valve movements. The optimizer solution should be used only as an advisory starting point. The user must add appropriate noise band and watch the PID output ROC before finalizing the PID tuning constants to be input into the DCS.

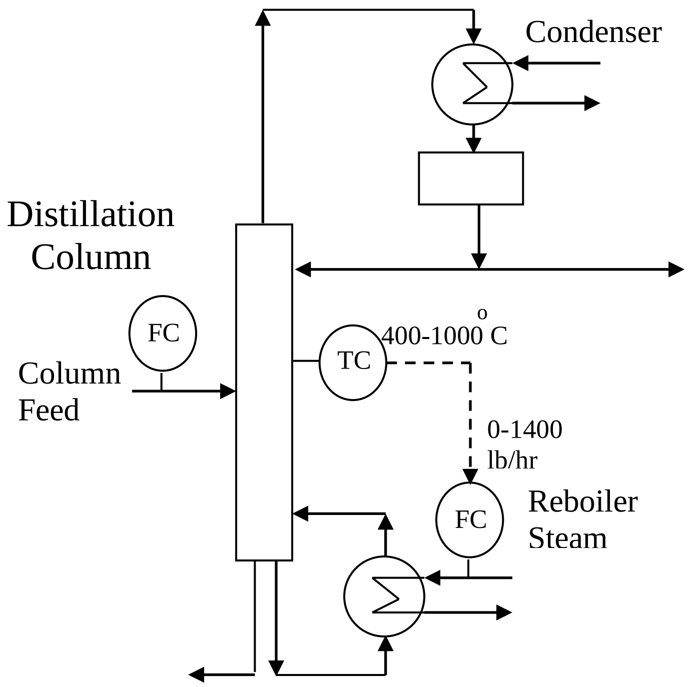
    This complete simulation can be restored by clicking on the Open Case File icon and then selecting Ex4.pid.

6.0 TUNE A TEMPERATURE CONTROL PID

The following exercise is designed to train the user on how to tune purity (correlated with temperature) control PID loops.

Temperature at Tray#27 is controlled by manipulating the reboiler flow (FC). See Figures 3A and 3B below.

Figure 3A. TC-FC Cascade Control Strategy

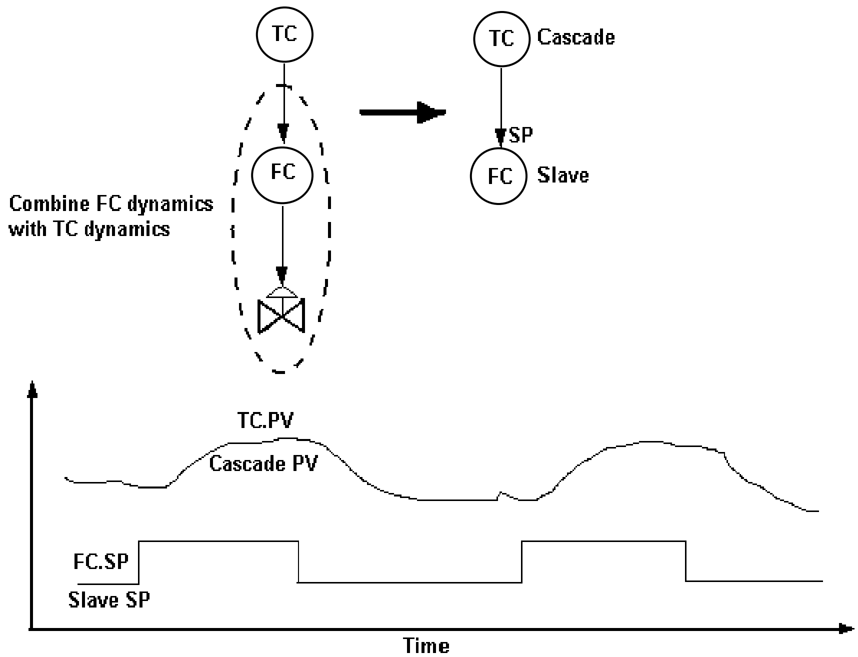


The FC flow range is 0-1400 lb/h. The FC has been well tuned already. The temperature (CV) range is 400 –1000°C. Temperature typically runs at 685°C.

Dynamics between FC setpoint and temperature are as follows: dead time = 4 minutes, time constant = 25 minutes. If the FC setpoint is changed by 5.0 lb/h, the total change in temperature at the new steady state is 12°C. Hint: process gain = (delta CV) / (delta MV); CV is the temperature and MV is the steam SP. Find the optimum PI and PID tuning parameters for the TC.

Since you have worked through step-by-step procedures and examples above thus far, this tuning problem is for you to work on your own. Recommended tuning parameters are given below, please do your calculations on your own first before seeing the answers provided.

Figure 3B. TC-FC Cascade Loop Dynamic Relationship



Optimum (aggressive) PI (IAE): P= 0.58, I = 27.
Recommended DCS tuning with PI only: P=0.2, I=25.
Optimum (aggressive) PID(IAE): P= 0.57, I = 30, D=1.5

Recommended DCS tuning with PID: P=0.2, I=20, D=0.25

This complete simulation can be restored by clicking on the Open Case File icon  and then selecting Ex5.pid.

7.0 TUNE A LEVEL CONTROL PID

This section simulates a level control (LC) PID loop. The LC dynamics are characterized by zero-order transfer functions, also called ramp-type or integrating-type of transfer functions. Zero-order transfer functions do not have time constants. To simulate a LC loop, first we need to estimate the ***Ramp Rate***. Ramp rate can be determined from a short plant test or may be calculated from the level sump geometry. The plant test procedure is as follows:

Put the LC in manual mode when conditions are relatively stable. Make a step change in the LC valve position by 2-5%. Wait for about 5-10 minutes. ***Ramp Rate*** is calculated as ***change in level / change in valve / time***. The step test in manual mode was used to define and explain the concept of the ramp rate. The PITOPS TFI (System Identification) module can identify the ramp rate from both closed-loop data (with the LC in Auto or even Cascade mode), or open-loop data (with the LC in Manual mode). Once the zero-order transfer function has been identified by PITOPS-TFI, PITOPS-PID can be used to simulate the LC PID loop and optimize the PI or PID tuning parameters.

Consider a LC that controls level in a distillation column sump by manipulating flow out of the column sump. The LC output manipulates the valve directly. The CV is the level with range of 0-100%. The MV is the valve, with range also 0-100%. The ramp rate is 0.05 (%level / %valve / minute). See Figure 4 below showing how the ramp rate is calculated. Dead time is 2 minutes. The procedure to determine the tuning constants for the LC is given below.

1. Click on the <u>New Case File</u> icon located near the top left corner of the screen. This clears the screen values and prepares for a new PITOPS-PID example. On the main screen, set <u>Simulation Time</u> to 800 minutes.

2. We will first configure a zero-order transfer function and examine the open-loop level response.

   Under <u>Process Transfer Function</u>, on right side of the screen, set <u>Delay</u> to 0 minutes, set <u>Gain</u> = -0.05 (% level/ % valve position /minute). <u>Tau1</u> and <u>Tau2</u> must be both zero.

   Set <u>SP Old</u> and <u>SP New</u> to 55% (initial level).

   Under <u>PID Tuning Parameters</u> on right side of the screen, set <u>P</u> = 0 (no PID action- manual mode). At this stage we want to demonstrate the open loop response with no PID action.

   Set <u>Valve Bump</u> = -5% (this means that at time = 0, the valve is bumped down by 5%, going from 50% to 45%).

   Click <u>Simulate</u> . Note the PV (indicating the tank level) in the top left plot. The level changes from 55% to 80% in 100 minutes due to 5% change in valve position.

   The ramp rate = (80 - 55% level)/(45-50% valve position)/(100 min) = -0.05 (%/%/min). This visual check matches with the entered ramp rate of -0.05.

3. Now we will make a SP change in automatic mode. Set <u>Valve Bump</u> to zero. Change <u>SP New</u> to 60%. Set <u>Delay</u> to 2 minutes. Under <u>PID Tuning Parameters</u>, set <u>P</u> = 0.5, <u>I</u> = 15 minutes.

Click Simulate. Examine the level PV, SP and OP. The setpoint is changed from 55% to 60%. Control response is rather oscillatory.

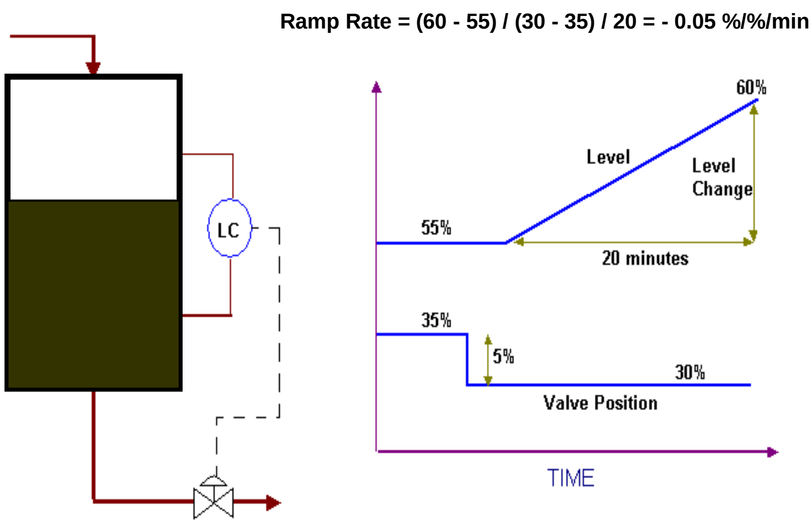
Click PID Tuning Criteria / Optimization icon and click on PITOPS-RO tuning method. This option is a good tuning option for zero-order (ramp) integrating transfer functions like liquid level control.

Notice that the new SP is achieved very crisply. Notice also that the optimizer has moved the Integral tuning constant to a very high value (no integral action). This is because for SP changes only with no disturbances, mathematically, a zero-order transfer function can be well tuned with proportional only control action. In practice though, to control well in the presence of disturbances, some integral control action is necessary.

Notice that the valve position before and after a setpoint change is the same (in this case 50%). This is an important characteristic of zero-order transfer functions – for SP change, the initial and final valve positions will be the same.

Try P = 2, I = 50. Click Simulate. Now the control action looks smooth, fast and stable. These are acceptable tuning values.

Figure 4. Level Control Loop



4. Now add a pulse and a ramp disturbance. Make sure that the tuning is good for both setpoint changes and disturbances. For LCs, handling disturbances is more important than setpoint changes.

Click Disturbance Transfer Function button. Under Disturbance Signals box click ON for Pulse. Set Start Time = 300 min, End Time = 500 min, Width = 200 min, Change = 5%.

Also, click ON for Ramp. Set Start Time =200 min, End Time = 2000 min, Rate = 0.2 %/min, Change = 1000.

5. Under Disturbance Transfer Function box, set Gain = 1.0 and Tau1 = 1.0.

6. Click Simulate . Examine the PV, SP and OP trends for the PID level controller. Notice how the PID tries to reject the disturbance.

   See the Disturbance Signal in the top right window showing the pulse and ramp signals.

   Set P = 0 (PID disabled with zero gain). Click Simulate . Examine the level PV and the disturbance signal. Notice that with the PID in manual, the level is directly affected by the disturbance.

   Set P = 2, I = 10. Click Simulate . Observe control action. Click PID Tuning Criteria / Optimization icon and click on PITOPS-IAE. See the PV, SP and OP trends with the new PI parameters.

   Now add derivative action. Set P = 2, I =10, D = 0.5. Click Simulate . Examine control action. Click PID Tuning Criteria / Optimization icon and click on PITOPS-IAE. Note the new PID parameters and remember the control response.

   Note that the PID parameters provide god control. In a real process, we could use P = 3, I = 20 and D = 2.

   Now we can add some noise to the PV signal to make it look like in a real plant. Click PV Signal Noise . Increase Single (Slave) PV Noise to about 0.2. Click OK and Simulate . Notice that now the valve flickers around in response to the noise.

7. Click PID Tuning Criteria / Optimization icon . As explained earlier, the PID Tuning Criteria calculates PID tuning parameters based on various popular published criteria known by the process control research community. Note that in case of zero-order transfer functions (as in this case), when both Tau1 and Tau2 are zero, only four options are available under the PID Tuning Criteria: IMC-PID, PITOPS-IAE, PITOPS-ISE, PITOPS-ITAE and PITOPS-RO. Other options (Ziegler Nichols – ZNOL and Cohen Coon- CC, both of which were available for the first order and second order transfer function cases) are not available under the zero-order transfer function case. Click on the IMC-PID option. Note down the PID tuning parameters from this IMC-PID option. Compare the PID parameters against those calculated by using the PITOPS optimizer by clicking on the PID Tuning Criteria / Optimization icon and click on PITOPS-IAE and PITOPS-ITAE.

   Try different PID values in the presence of typical noise and determine the best values for downloading into the DCS.

   This complete simulation can be restored by clicking on the Open Case File icon and then selecting Ex6.pid.

8.0 TUNE A CASCADE PID

This section simulates a cascade PID loop. The example selected is a distillation column, where the bottoms impurity is controlled by an online analyzer PID (AC, for analysis control) cascaded to a TC which in turn is cascaded to the reboiler steam FC. See Figure 5 below. It is assumed that the fast FC is well tuned already. Tuning parameters for the TC and AC are to be determined.

To tune the TC and the AC, first the transfer function between the FC.SP and the temperature must be known. This can be identified by conducting a few pulse tests on the setpoint of the FC. Once the transfer function is known, the TC can be tuned using the procedure provided for tuning a single PID loop. After satisfactory tuning of the TC, the transfer function between the TC setpoint and the online analysis may be identified by conducting pulse tests on the TC setpoint.

Consider an example where the transfer function data are as follows:

Transfer Function	Delay	Gain	Time Constant
FC.SP - TC.PV	7 min	1.3 °C/(t/h)	25 min
TC.SP - AC.PV	20 min	0.4 ppm/°C	110 min

Instrument Ranges:
FC 0-500 t/hr
TC 0-200 °C
AC 0-50 ppm

Based on the above information, we can build a cascade simulation and determine the PID tuning constants for the TC and AC. Procedure is as follows:

1. Click on the New Case File icon located near the top left to start a new PITOPS run. Set Simulation Time to 800 minutes.

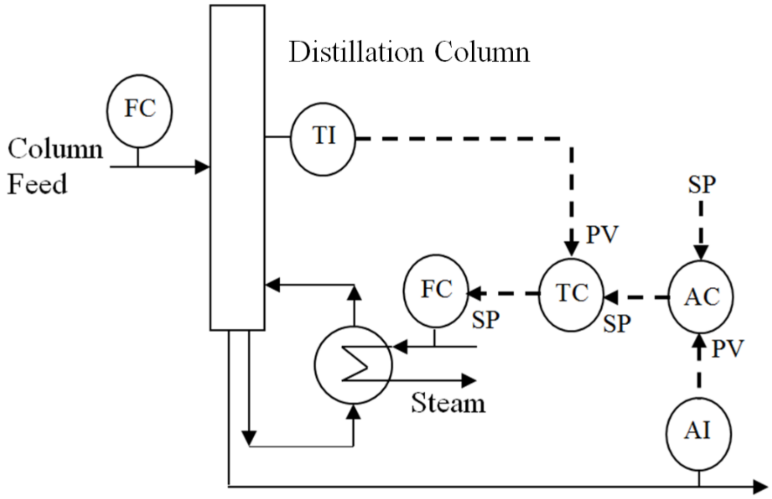
2. On right side of the screen, enter Process Transfer Function Parameters for the TC (7, 1.3, 25). Click Single PID, set CV Range and MV Range. The MV range for the TC is the FC range, 0-500 t/hr. The CV range for the TC is 0-200 °C.

3. Click on PID Configuration icon. Keep the PID Scan Time at 1 minute and keep the PID Tuning Time Unit at Minute. Keep the PID Equation to be equation B0. Click OK.

4. On right side of the main screen, set SP Old = 110 °C and SP New = 115 °C (select reasonable setpoint change typical in the plant based on process knowledge).

5. Click Simulate with default P and I values for the TC. Click PID Tuning Criteria / Optimization icon and click on PITOPS-IAE to determine PI values based on IAE criterion. Use derivative action also (non-zero D). Based on process knowledge de-tune the tuning to avoid excessive changes in the reboiler steam flow. Add disturbances and noise if necessary. Finalize the best TC tuning parameters. Now the TC tuning may be considered complete.

Figure 5. Cascade Control Loop



6. Now click on Cascade PID button located near top right corner of screen. A new column for the cascade PID appears. Enter Transfer Function Parameters for the cascade PID AC (20, 0.4, 110).

   Click on the Cascade PID Configuration icon located in the top toolbar. Set the CV Range and MV Range as follows: The MV range for the AC is the TC range, 0-200 °C. The CV range for the AC is 0-50 ppm.

   Keep the PID Scan Time at 1 minute and keep the PID Tuning Time Unit at the default selection of Minute. Leave the PID Algorithm to be equation B0. Click OK.

   Under the Cascade column on the far right side of the screen, set SP Old = 20 ppm and SP New = 25 ppm (select reasonable setpoint change typical in the plant based on process knowledge).

7. Now we are ready to watch the simulation and the control action. Set Cascade P = 0.5, I = 25, D = 0. Set Simulation Time to 800 minutes. Click Simulate. Notice that now the cascade PV and SP are displayed on the screen. See the TC and the cascade AC trends.

8. Now we want to optimize the cascade PID tuning parameters. Click PID Tuning Criteria / Optimization icon and click on PITOPS-IAE to run the optimizer to determine the cascade PID parameters. Notice the improved control of the cascade loop after completion of the optimizer.

9. Try different PID values for the slave and cascade PIDs. Add noise and external disturbances. Compare different Error values and OP ROC for the slave TC (located near the right side of the screen). Try increasing delay and gains in the loops to account for nonlinearities or possible changes in dynamics. Finalize tuning parameters after running various scenarios, typically seen in the real plant.

10. Under the far right column on the main screen (under Cascade column), see the SP ROC

field. SP ROC stands for *Setpoint Rate-of-Change*. This allows the Setpoint to be ramped slowly instead of an abrupt step. Change the SP ROC for Cascade to 0.1. Click Simulate . Notice now the Setpoint is ramped from 20 to 25 in 50 minutes. The change in Setpoint is 25-20 = 5 and is made over 50 minutes and 5/50 = 0.1 which is the specified SP ROC value.

11. Under the far right column on the main screen (under Cascade column), click on More under the Filter value and you will see additional parameters related to the PID algorithm for Cascade PID. These are Derivative PV Lag, Auto Derivative Filtering ON/OFF, Error Deadband, Gap Gain, Gap Low and Gap Hi. These are all explained in detail in Part C of this manual.

This complete simulation can be restored by clicking on the Open Case File icon  and then selecting Ex7.pid.

9.0 FEEDFORWARD TRANSFER FUNCTION

This section illustrates how to use the feedforward transfer function. Click on Map Data Entry icon labeled in top-bar to see the location of the feedforward transfer function and its input and output signals.

1. Click on the New Case File icon located near the top left to start a new PITOPS run. Set Simulation Time = 800 Minute.

2. Let's assume that the setpoint at start time of simulation was 50. Set SP Old and SP new to 50. If you click on the PID Configuration icon in top toolbar, then leave all the values and selections at their default values (do not make any changes). Click OK.

   Note that the time unit is Minute for both DCS PID tuning and Simulation Time.

3. Specify the Process Transfer Function parameters for the main process located on the right side of the screen.

   Set Delay = 15 minutes, Gain = 2.0 and Tau1 = 50 minutes.

4. Now define the Disturbance Transfer Function parameters located near bottom left side of the screen.

   Set the disturbance transfer function Delay = 20 minutes, Gain = 1.0 and Time Constant = 100.

Transfer Function	Delay	Gain	Time Constant
Main	15 min	2.0	50 min
Disturbance	20 min	1.0	100 min

5. We will add a pulse disturbance. Go to Disturbance Signal box and click ON to activate Pulse. Set Start Time = 100, End Time = 400, Width = 300, and Change = 10. Keep Pulse disturbance to appear as Regular signal. Click on Simulate . Notice that the PV trend (upper left plot) is deviating from a SP, this is because of disturbance signal.

6. As shown below, calculate the feedforward transfer function parameters based on the values of the main process and disturbance transfer function parameters.

   The equations to calculate the feedforward parameters are given below:

   $Delay_{FF} = Delay_{DIST} - Delay_{MAIN} = 20 - 15 = 5$

   $Gain_{FF} = Gain_{DIST} / Gain_{MAIN} = 1.0 / 2.0 = 0.5$

   $LAG_{FF} = Time\ Constant_{DIST} = 100$

   $LEAD_{FF} = Time\ Constant_{MAIN} = 50$

where:

FF	= Feedforward transfer function
DIST	= Disturbance transfer function
MAIN	= Main transfer function

6. If you click on the Feedforward Transfer Function button you can enter the above values under Feedforward Transfer Function (Delay = 5, Gain = 0.5, Lead = 50, Lag1 = 100 and Lag2 = 0) located near the bottom of screen.

   Or, if you select Calculate located below "Input From" under Feedforward Transfer Function, then these values are automatically calculated based on the values of the process transfer function and the disturbance transfer function.

   If you select User located next to Calculate, then you can manually enter the Feedforward Transfer Function values. Click on Simulate.

7. Click on the icon in the top-bar labeled Map Data Entry to view the block diagram of the control schematic. This schematic shows the location of all transfer functions and signals. Use this diagram as a guide while configuring the simulation and for conveniently entering the various parameter values.

   Now all configuration data required to simulate the feedforward transfer function have been entered. Now, we can run the simulation and examine the plots.

   Under Tuning, on the right side of the screen, set P = 0.0 (we want to disable the PID so that we can watch the feedforward action only without any PID contribution).

   Click on Simulate . Notice that the PV trend (upper left plot) is flat, this is because the feedforward signal completely compensates (cancels) the disturbance signal. Notice that the OP trend (middle left plot) is the feedforward signal contribution.

   See the Disturbance signal in the top right window. Even though a disturbance signal is present, there is no apparent effect on the PV (top left plot). This is because the disturbance signal is completely compensated (cancelled) by the feedforward signal.

   See the Feedforward signal in the middle right plot. This signal is the output signal from the feedforward transfer function which becomes the input signal to the process transfer function. Here there is no PID control contribution because the PID's proportional gain is zero.

8. Change the transfer function parameter values for both Process Transfer Function and Disturbance Transfer Function. and then try different values for the Feedforward parameters. You can either select Calculate or the User options while you experiment. Note that with any combination of transfer function values, if the feedforward parameters are calculated based on the above equations, then the disturbance is completely compensated, and the main PV is a flat line (unchanged). If parameters do not satisfy the equations, then the disturbance does affect the main PV signal.

This complete simulation can be restored by clicking on the Open Case File icon and then selecting Ex8.pid.

10.0 MODEL-BASED CONTROLLER

This section illustrates how to use the model-based controller feature. This feature can be used not only for model-based control simulations but also to simulate IMC (Internal Model Control) schemes and for dead-time compensation on loops with long dead times (particularly when the ratio of dead time to time constant is large). Figure 6 illustrates a dead time compensation application using the model-based controller scheme as follows:

Pressure in a gas pipeline is controlled by adjusting the valve position of the supply pipeline as shown above. Distance between the pressure measurement and the gas tank is very long resulting in long time delay. With the PC in manual mode, if gas supply valve position is changed, the pressure downstream changes after a long delay. The delay can be compensated by using the model algorithm shown in the control block diagram above. The following procedure is used to configure the model-based control algorithm in PITOPS-PID:

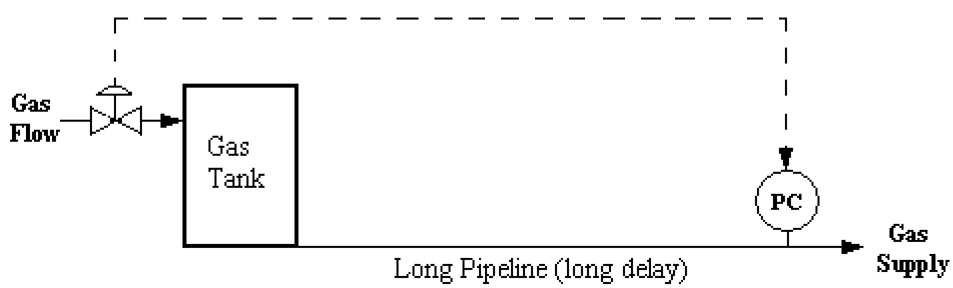
1. Click on the <u>New Case File</u> icon located near the top left to start a new PITOPS run.

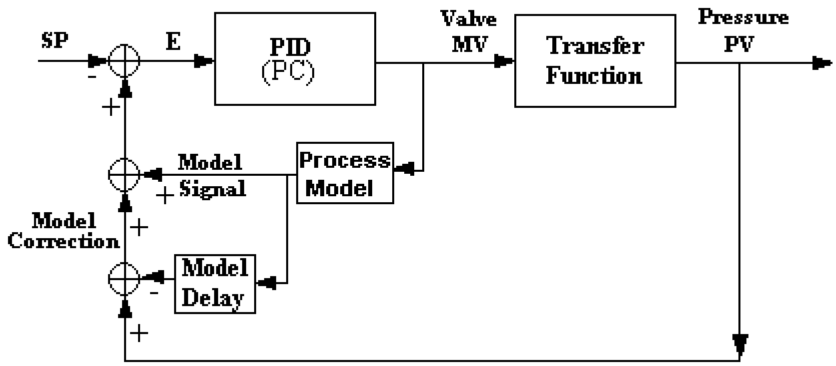
2. Let's assume that the setpoint at start time of simulation was 45 and we want to simulate a setpoint change to 50. Set <u>SP Old</u> to 45 and <u>SP new</u> to 50.

   Click on <u>PID Configuration</u> icon located in the top toolbar. Leave everything at the default values and default selections. Click <u>OK</u>.

3. Assume the following transfer function parameters for the main process: In the right side <u>Process Transfer Function</u> box, set <u>Delay</u> = 40 minutes, <u>Gain</u> = 2.0 and <u>Tau1</u> = 20 minutes. Note that the time unit in this example is minutes for the PID controller and Simulation Time.

Figure 6. Model-based Controller Schematic





4. Set Simulation Time to 500 minutes. Click Simulate to watch the setpoint change. Control action appears rather oscillatory. Click on PID Tuning Criteria / Optimization icon and click on PITOPS-IAE. The oscillations are eliminated due to better tuning determined by PITOPS, but the setpoint change looks rather sluggish. Try different PI or PID parameters to improve the setpoint change control action. Because of the long delay (40 minutes) it is not possible to tune the PID aggressively. Long delay causes unfavorable dynamics in the loop. Proportional gain must be reduced for the loop to be stable. However, the effect of the dead time can be compensated using the model-based algorithm. The algorithm allows increasing the proportional gain of the PID thus enabling tighter control.

5. Specify the Model Transfer Function parameters located near the bottom center of the screen. Set Model Transfer Function Delay to 40, Gain to 2.0 and Time Constant to 20 (same parameters as the process transfer function entered in Step 3 above).

6. Click on Simulate . Notice that the control action for the setpoint change now looks different as compared to before activating the Model transfer function.

   Click on the icon in the top-bar labeled Map Data Entry to view the block diagram of the control schematic. This schematic shows the location of all transfer functions and signals. Use this diagram as a guide while configuring the simulation and for conveniently entering the various parameter values.

   The Gain of 2.0 and Time Constant of 20 entered in Step 5 above constitute the box labeled Internal Model. The PID output is fed to the Internal Model transfer function which has a gain of 2.0 and Time Constant of 20 and zero dead time. The Model Delay box is a pure delay function with delay of 40 minutes (specified in the Model Transfer Function).

   See the bottom right plot showing the Model Prediction. This is the same signal as the output signal passed from the “Internal Model” and "Model Delay" box labeled on the Control Schematic seen upon clicking the Map Data Entry icon .

   The response appears rather sluggish. It is obvious that the tuning could be made more aggressive. Click on PID Tuning Criteria / Optimization icon and click on PITOPS-IAE. Notice that the new tuning is rather aggressive. This is possible because the model-based strategy has eliminated the effect of the dead time. The 40-minute dead time in the process transfer function has been effectively "reduced" to 0.

The smaller the dead time, the more aggressive a PID can be tuned. Therefore, after adding the dead time compensation, the optimum IAE tuning parameters happen to be so aggressive. In practice, such aggressive tuning cannot be used in the DCS on the real plant.

Try different tuning parameters and run the simulation. Examine the PID output rate of change and make sure that it would be acceptable on the real process. Proportional gain = 1.0 and Integral = 20 appear to be good stable PI tuning parameters. In this example, because of the model-based controller, the proportional gain can be increased by about four times compared to without the compensation.

7. Note that the Model Transfer Function parameters are set to be the same as the Process Transfer Function (dead time = 40, process gain = 2.0 and time constant = 20). If the model transfer function parameters differ from the main process transfer function parameters, then the control loop quality deteriorates. In case of very large differences, the loop could even become unstable.

   To illustrate this concept, change the Model Transfer Function parameters as follows: Set Delay = 20 and Gain = 1.0. Now there is a large difference (error) between the Model Transfer Function parameters and the Process Transfer Function parameters.

   Click Simulate  to run the simulation. Now the control loop is unstable- the PV oscillations keep growing larger and larger. The error between the two transfer functions causes out-of-phase dynamics, thus causing the loop to become unstable.

   For the model-based strategy to be useful, the transfer function parameters must be accurately known, at least within 15 - 25% accuracy.

This complete simulation can be restored by clicking on the Open Case File icon  and then selecting Ex9.pid.

11.0 VALVE STICTION SIMULATION AND PID OPTIMIZATION

Control valves can be defective and exhibit stiction problems. Valve Stiction is explained in Part C below. Please read that section before proceeding further here.

This section illustrates how to optimize PID tuning in the presence of valve stiction.

1. Click on the Open Case File, select the file Ex10.pid and then click on Open (the file Ex10.pid is provided with the PITOPS-PID software). This example shows a FC (Flow Control) PID simulation with a SP change from 70 to 90 kg/hr. A pulse and a ramp disturbance are also active as can be seen in the disturbance plot (top right window).

   On the main screen, under Process Transfer Function, notice that Delay = 5 seconds, Gain = 3.0 kg/hr/% and Tau 1 = 50 seconds. Note that the time unit for DCS PID tuning, simulation time and transfer function parameters are all in **seconds**. The flow unit is kg/hr flow rate. The FC output goes to a control valve (0-100% range).

   Go to Disturbance Signals window and observe Pulse and Ramp configured disturbances.

2. PID equation is Equation B0; the PID scan time is 1 second. Initial tuning is P = 1.0, I = 15 second and D = 0 second. Click on PID Tuning Criteria / Optimization icon and click on PITOPS-RO to optimize the tuning parameters. Optimum PI tuning is P = 3.4 and I = 26.

   Note 1: The ***integral*** is in ***seconds*** since time unit is seconds in this example.

   Note 2: The ***Reduced Overshoot*** is the error criterion for the tuning optimization.

3. Near the bottom right corner of the screen, set Valve Stiction = 20. Click on PID Raw Output button (next to Valve Stiction). Now the bottom left plot window will display PID Raw Output. The button near the bottom right screen corner now will display PID Contribution. You can toggle from PID Raw Output to PID Contribution by clicking (toggling) this button.

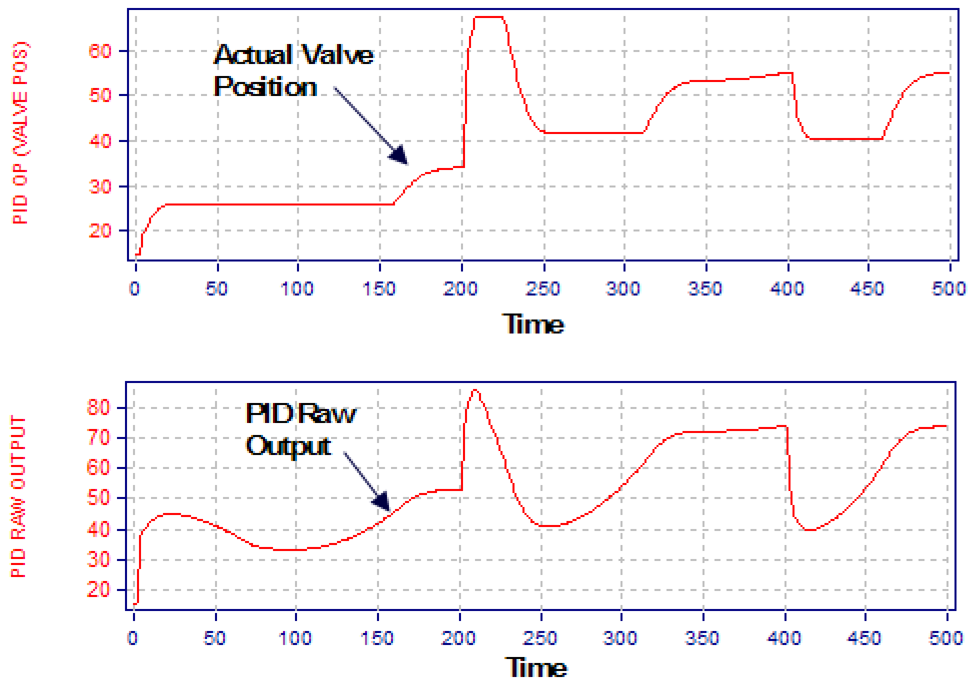
4. Click Simulate. Notice the difference between the left middle plot and the left bottom plot. The left bottom plot shows the raw PID Output (OP) going to the valve. The left middle plot shows the actual valve position. See Figure 7 below.

   As explained in Part C, valve stiction is caused by sticking, loose play or poor linkage in the control valve hardware. When the PID OP changes, until a certain minimum change has taken place, the valve does not move. Then, if the PID OP changes direction, then again, a certain minimum change in the PID OP must occur before the valve sees a change. Therefore, you see the “flat lines” in the PID OP (Valve Pos) Plot. During the time the Valve Pos is “flat”, the PID OP is changing to cover the Stiction Value.

5. Click PID Tuning Criteria / Optimization icon and click on PITOPS-IAE. Notice that now optimum parameters in the presence of valve stiction show higher P (stronger proportional action) and higher I (weaker integral action). *In general, a valve with stiction needs more proportional action and less integral action*.

In a plant, you can estimate valve stiction by conducting "bump" tests on the valve until you see the PV change (this is proof that the valve finally has moved), you can attach temporary valve feedback position indicators and compare the PID OP with the valve position, or you can also use PITOPS-TFI (System Identification) software. PITOPS-TFI is a separate software product that accompanies PITOPS-PID.

Figure 7. PID Raw Output and Actual Valve Position with Valve Stiction



This final optimized simulation with valve stiction can be restored by clicking on the Open Case File icon and then selecting Ex11.pid.