PITOPS TFI HOMEWORK LAB EXERCISES

CONTENTS

PART B: **EXAMPLES ON TRANSFER FUNCTION IDENTIFICATION**

1.0   INTRODUCTION

This part helps the user to get started on how to identify transfer functions with PITOPS. Several examples are provided on how to configure PITOPS to identify transfer functions based on trend data. Detailed step by step instructions are provided on each example.

Example #1 shows how to identify a first order transfer function with time delay.

Example #2 shows how to identify a second order transfer function with time delay.

Example #3 shows how to simultaneously identify three transfer functions with time delays using closed-loop data.

Example #4 shows how to identify control valve stiction.

Example #5 shows how to fit transfer function models to step response coefficients.

Examples #6, #7 and #8 show how to identify transfer functions accurately using plant data contaminated with noise, drift and unmeasured disturbances.

After configuring these examples, the user will be able to use PITOPS-TFI for new applications.

2.0   EXAMPLE #1 - IDENTIFY FIRST ORDER WITH DELAY TRANSFER FUNCTION

This example illustrates how to identify a single first order transfer function. This example shows reactor temperature control.

If steam flow is increased, reactor temperature increases (transfer function gain is positive).

The steam flow is the input signal to the transfer function and the temperature is the output signal from the transfer function. See Figure 1.

We want to identify the transfer function between steam flow and temperature based on trend data on these two variables. The tagname of the steam flow PID in the DCS or PLC is FC125 and the tagname for the temperature is TI110.

The DCS or PLC data extraction software needs to create an Excel file EX1 PLANT DATA.xls. This file is supplied with the PITOPS-TFI software to show the file format and structure.

The second column contains temperature data (DCS tagname TI110).

The third column contains the steam flow setpoint data (DCS tagname FC125). The two trends are shown in Figure 2.

Note that the first column in the file EX1 PLANT DATA.xls is ignored but this column is required since at start time of PITOPS-TFI, we specified that data starts in column #2.

The procedure for configuring PITOPS to identify the transfer function is given below:

Figure 1. Temperature Control Example
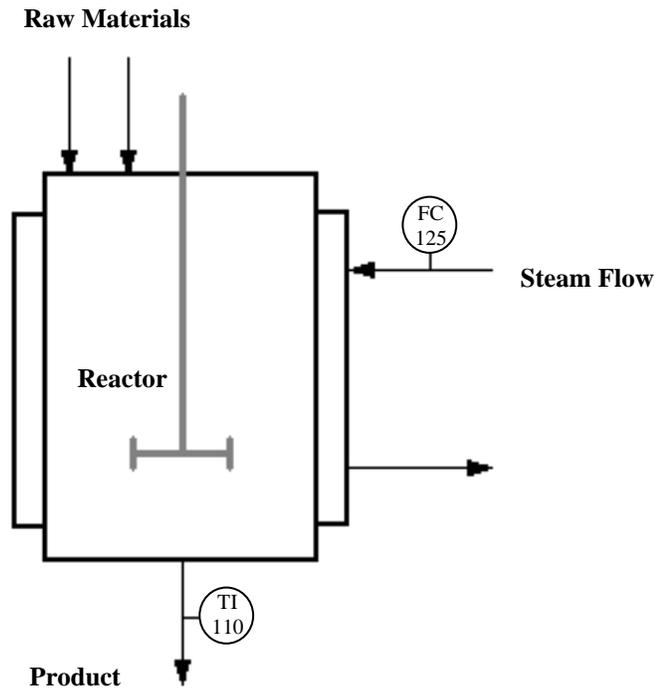
Figure 2. Steam versus Temperature Data
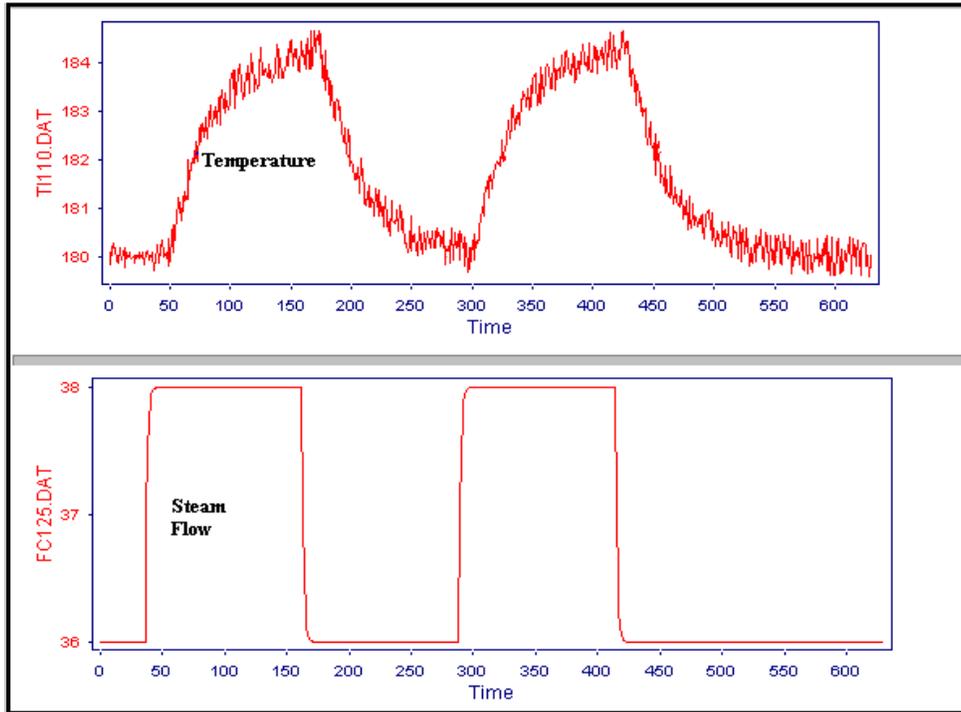
Step #1: **Plant Data Files**

Go to the PITOPS directory, where all PITOPS files are located. Open and examine the file EX1 PLANT DATA.xls.

The first row contains tagname labels. The second and third rows in this file are intentionally left blank but they can be used to specify tagname descriptors and engineering units (these two rows are optional and may be left blank). This file format can be changed as necessary; the procedure is explained in Part C, Section 3.4.

The first column in this file contains the data time stamps. Note that all time stamps in the column happen to be the same (this is intentional). PITOPS-TFI does not read this time stamp column. However, since most data historians reserve the first column for time samples, in order to keep the file format compatible, PITOPS-TFI assumes that the first column is reserved for time stamps. PITOPS-TFI does not read the content of this first column but reads data starting from the second column. Note that the starting row and column for data reading in this example is column=2 and row=4. If you need to start reading data from a different row and/or column location, please see the procedure is explained in Part C, Section 3.4.

Sample time between consecutive data rows depends on the data historian and its configuration. Typical sample times are 1 second, 2 second, 5 second, 10 second, 1 minute, etc. See step #3 below on how to specify the correct data sample time.

The actual process data values start from the fourth line onwards and go until the end of the file.

Go to the end of the file. Note that the number of data points in all columns must be the same. Maximum number of data points cannot exceed 50,000.

In this example, we have only one MV (steam flow). PITOPS-TFI can process up to three MVs.

Now start the PITOPS-TFI by double clicking on the icon.

Step #2: **Specify Filenames**

Click on File, click New Case File or click on the icon ▢. Click Yes inside the popup window. Loading New Case File erases data from any previous work prepares for a new case.

Click on File / Plant Data File or the icon 🖺 and click on the file EX1 PLANT DATA.xls. Click Open.

Notice that the temperature data can be seen in the topmost plot (red colored trend). The plot is labeled Output (CV) on the left side.

The steam flow setpoint data can be seen in the bottom window (also in red color). The plot is labeled Input1 (MV1) on the left side.

Near the top left corner of the screen, see label inside the box CV1: TI110. Click on this box and then you will see two choices – TI110 and FC125. By selecting TI110, then TI110 becomes the CV (Output) and by selecting FC125, then FC125 becomes the CV (Output). In this example, CV needs to be TI110, but this step demonstrates that you can make any column from the plant data file to be CV or MV. You can click on the button MV1: FC125 and you can change the MV. This is new for Version 8.1.

Step #3: **Start Time, End Time and Sample Time**

Near the top of the screen, note that the Start Time is 0 and End Time is 634. This is because we have 634 data points in the data file EX1 PLANT DATA.xls. If we keep the 0 - 634 settings, this means we want to use the entire window of data (0-634) for analysis. If portions of the data were bad, or we wanted to use smaller piece of the total data set, then we can change the Start Time and End Time to something else.

To the right of End Time, notice that Sample Time is 1. This means that the sample time in the data file EX1 PLANT DATA.xls is 1 time unit. In other words, inside the data file, the data rows are spaced apart by one time unit. The time unit could be millisecond, second, minute or any other time unit.

When using a new plant data file at your plant, if the sample time were 5 seconds, then you will set Sample Time to 5. Then all the time-dependent transfer function parameters: Delay time, Tau1, Tau2, and also the Start Time and End Time will be all multiplied by the sample time (multiplied by 5 in this illustration).

Step #4: **Zoom Feature**

PITOPS-TFI provides powerful zooming feature. With left mouse, click in the topmost plot window somewhere around time = 30 and temperature (CV) = 182.

Keep the left mouse key pressed and draw a rectangle towards the second coordinate close to time = about 60 and temperature (CV) about 179.5 and then release the mouse key.

The rectangle is now nicely zoomed. Now click and hold the right mouse key and move the mouse up, down, right, left at any angle to scroll the screen.

Zoom also similarly for the steam flow plot.

Step #5: **Transfer Function Parameters**

Zooming on the data trends as explained above helps to visually estimate the transfer function parameters.

Based on visual inspection of the data trends in this example, the delay appears to be 5 - 12 minutes. We can also see that the time constant (Tau1) is about 20 minutes. Also notice that for the 2.0 change in steam flow (MV1), the temperature (CV) changes by approximately 4.0. This means that the process gain is approximately 4.0/2.0 = 2.0.

On the right side of the screen, inside the Transfer Function #1 box, set initial guess for Delay = 5 minutes, Gain = 1.5 and Tau1 = 20. We need to specify some reasonable initial approximate values for all four transfer function parameters. Leave Tau2 at zero, since here we are assuming a first order transfer function.

Instead of setting the initial guess for transfer function parameters manually as explained above, PITOPS-TFI provides a convenient function to automatically set the initial transfer function parameters. To use this function, click on the icon for Transfer Function Model Order in the top toolbar. This function allows you to select the transfer function order – Zero Order, First Order or Second Order. You can also select the sign of the process gain (positive or negative). Based on your knowledge of the process, chose the transfer function order. PITOPS-TFI automatically sets the process gain, dead time and time constant to some reasonable non-zero values as the initial guess.

This example is a first order transfer function with positive gain. So here, click on Transfer Function Model Order in the top toolbar, click on First Order, Positive Gain and then click Ok.

Step #6: **Run Simulation**

Click on Run / Simulate or click on the icon . Notice that the blue trend (in the topmost plot) which was a flat line before now is somewhat similar to the red trend. The blue trend is the temperature signal (CV) prediction in response to the steam flow (MV1) input signal and the transfer function parameters.

The blue trend is also called Model Prediction. PITOPS reads steam flow data (MV1), temperature data (CV) and transfer function parameters to generate the model prediction. Note the value of Error located near the right side of the screen. This is the difference between the blue and the red colored trends summed at every sample time (one minute in this case). If the blue and red signals were identical, (superimposed on top of each other), then Error would be zero.

Step #7: **Check Guessed Transfer Function Parameters**

Try different values of <u>Transfer Function #1</u> parameters. For example, set <u>Gain</u> = 5 while keeping other parameters unchanged. Click on <u>Run</u> / <u>Simulate</u> ⊞.

Notice that the blue colored trend expands significantly compared to the red. Obviously, we made the transfer function fit worse. Try different values for <u>Delay</u>, <u>Gain</u> and <u>Tau1</u> and study the impact on the simulation.

Step #8: **Identify Transfer Function**

Re-set the initial guess to: <u>Delay</u> = 5, <u>Gain</u> = 1.5, <u>Tau1</u> = 20. Click on <u>Run</u> / <u>Simulate</u> ⊞. Note the value of <u>Error</u> on the right side of the screen.

Click on <u>Run</u> / <u>Identify</u> or the icon 🔍 (<u>Identify Transfer Function Parameters</u>) to trigger the identifier (the identifier is the identification algorithm in PITOPS-TFI that identifies the transfer function parameters). Near the bottom left corner of the screen, a message appears: "**Identification in Progress, Please Wait…(Press Escape key to stop anytime)** ". After a short time, a message window pops up indicating successful identification. Click on <u>OK</u>. Note that in case the number of data points (End Time minus Start Time) is rather high (> 5000 samples), then the time needed to complete the identification may be too long (2-4 minutes). If you need to abort, then press the ESCAPE key to abort the transfer function identification.

Notice the new and improved <u>Transfer Function #1</u> parameters determined by the PITOPS-TFI identifier. The <u>Error</u> value is lower than the previous case.

Notice that the blue colored trend (model prediction) in the top window now closely matches the temperature CV data (red colored trend). The transfer function parameters: Delay = 15, Gain = 2.1 and Tau1 = 31 fit the process dynamics well for this MV, CV pair of variables.

The PITOPS-TFI identifier consists of an identification algorithm that searches for the best transfer function parameters based on their starting values which we had specified earlier.

Try different values of initial transfer function parameters and click on <u>Run</u> / <u>Identify</u> 🔍 again. The identification algorithm may converge to slightly different values depending on the initial transfer function values. If the initial values of the transfer function parameters are very far from the optimum values, then the identification algorithm may not be able to identify good transfer function parameters and you will see a "Fail" message. In addition, the time required to complete the identification may be rather long (2 to 4 minutes) in some cases. If the identification is taking too long, abort the identification by pressing the ESCAPE key anytime. After aborting identification, or in case identification was not able to reduce the Error and generate improved transfer function parameters, then change the initial guessed values of transfer function parameters and click on <u>Run</u> / <u>Identify</u> 🔍 again.

Step #9: **Save Case File**

Now we can save all identified transfer function parameters and the plant data filename to a case file for future re-runs and continued analysis.

Click on the ■(Save Case File) icon. Alternatively, click on File / Save As. Enter any desired filename to save, with "TF" as filename extension (example, TEST1.TF). The "TF" filename extension is an abbreviation for "Transfer Function". Click on Save. Now a file with that name will be created. By saving the file, one can restore the complete example later conveniently.

A case file named EX1.TF has been provided with the PITOPS software. This is a case file with all configuration data from this example. To bring up this example, click on File / Open Case File or click on the icon ■ and then select EX1.TF.

Step #10: **Case File Notes**

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.

Step #11: **Select Trends**
Near the top right of the screen, you will see Select All and Unselect All. This example has only one input (one MV) and there is only FC125 selection option available. But if you have more than one inputs, (see Section 4 below), then you have the choice of selecting or unselecting from three inputs.

3.0   EXAMPLE #2 - IDENTIFY SECOND ORDER WITH DELAY TRANSFER FUNCTION

This example illustrates how to identify a single second order transfer function. This example illustrates distillation column product purity control. If reflux flow is increased, overhead product purity increases and vice versa. The reflux flow is the input signal to the transfer function and the overhead product purity is the output signal from the transfer function. See Figure 3 below.

We want to identify the transfer function between reflux flow and overhead product purity based on trend data on these two variables. The tagname of the reflux flow PID is FC631 and the tagname for the product purity is AI905.

The DCS or PLC data extraction software needs to create an Excel file <u>EX2 PLANT DATA.xls</u>. This file is supplied with the PITOPS-TFI software to show the file format and structure. The second column contains product purity data (DCS tagname AI905). The third column contains the reflux flow setpoint data (DCS tagname FC631). The two trends are shown in Figure 4. Note that the first column in the file <u>EX2 PLANT DATA.xls</u> is ignored but this column is required since at start time of PITOPS-TFI, we specified that data starts in column #2.

The procedure for configuring PITOPS to identify the transfer function is given below:

Figure 3. Reflux versus Overhead Purity Data
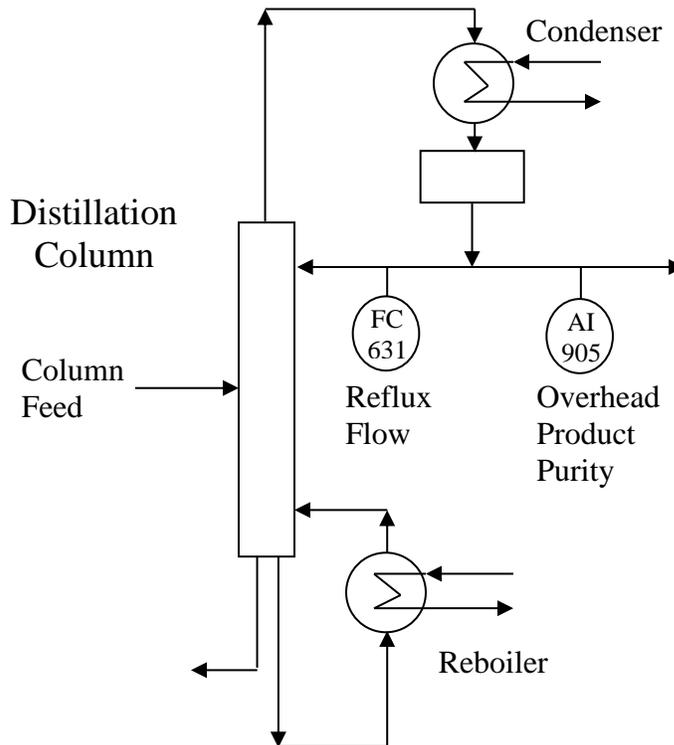
Step #1: Plant Data Files

Go to the PITOPS directory, where all PITOPS files are located. Open and examine the file EX2 PLANT DATA.xls.

The first row contains tagname labels. The sample time is known to be one minute in this case.

The second and third rows in the file are blanks and can be used to specify tagname descriptor and engineering units (these two rows are optional and may be kept blank).

The actual process data values start from the fourth line onwards and go until the end of the file.

Go to the end of the file. Note that the number of data points in all columns must be the same. Maximum number of data points cannot exceed 50,000.

In this example, we have only one MV (reflux flow). PITOPS-TFI can process up to three MVs.

Now start PITOPS-TFI by double-clicking on its icon.

Step #2: Specify Filenames

Click on File / New Case File or click on the icon [icon] and then click "Yes" inside the popup window. This erases data from any previous work prepares for a new case.

Figure 4. Reflux versus Product Purity Data
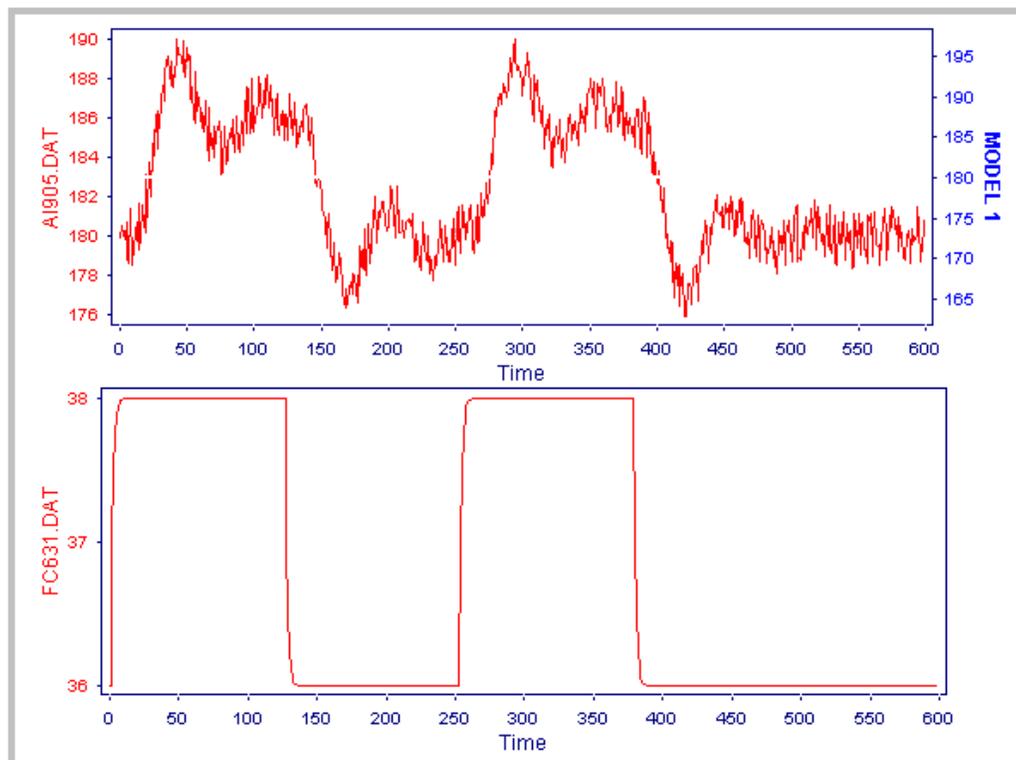
Click on File / Plant Data File or the icon 📄 and click on EX2 PLANT DATA.xls. Then click on Open.

Notice that the product purity data can be seen in the topmost plot (red colored trend). The plot is labeled Output (CV) on the left side.

The reflux flow setpoint data can be seen in the bottom window (also in red color). The plot is labeled Input1 (MV1) on the left side.

Near the top left corner of the screen, see label inside the box CV1: AI905. Click on this box and then you will see two choices – AI905 and FC631. By selecting AI905, then AI905 becomes the CV (Output) and by selecting FC631, then FC631 becomes the CV (Output). In this example, CV needs to be AI905, but this step demonstrates that you can make any column from the plant data file to be CV or MV. You can click on the button MV1: FC631 and you can change the MV. This is new for Version 8.1.

Step #3: Start Time, End Time and Sample Time

At the top of the screen, note that the Start Time is 0 and End Time is 599. This is because we have 599 data points in the data file EX2 PLANT DATA.xls. If we keep the 0 - 599 settings, this means we want to use the entire window of data (0 - 599) for analysis. If portions of the data were bad, or we wanted to use smaller piece of the total data set, then we can change the Start Time and End Time to something else.

Sample Time is 1 minute in this example because we know that the data in the plant data file are spaced apart at 1 minute time intervals.

Step #4: Zoom Feature

PITOPS-TFI provides powerful zooming feature. With left mouse, click in the topmost plot window somewhere around time = 0 and product purity (CV) = 190. Keep the left mouse key pressed and draw a rectangle towards the second coordinate close to time = about 175 and product purity (CV) about 175 and then release the mouse key. The rectangle is now nicely zoomed. Now click and hold the right mouse key and move the mouse up, down, right, left at any angle to scroll the screen.

Zoom also similarly for the reflux flow plot.

Step #5: Transfer Function Parameters

Zooming the data trends as explained above, helps to visually estimate the transfer function parameters. Based on visual inspection, the delay appears to be 5-12 minutes. We can also see that the settling time is about 120 minutes. Also notice that for the 2.0 change in the reflux flow (MV) the product purity (CV) changes by approximately 5.0 or 6.0. This means that the process gain is approximately 5.0/2.0 = 2.5.

Inside the Transfer Function #1 box, set initial guess for Delay = 5 minutes, Gain = 2, Tau1 = 15 and Tau2 = 15. We need to specify some reasonable initial approximate values for all four transfer function parameters. These transfer function parameters are initial guesses based on approximate knowledge of the process dynamics.

Instead of setting the initial guess for transfer function parameters manually as explained above, PITOPS-TFI provides a convenient function to automatically set the initial transfer function parameters. To use this function, click on the icon for Transfer Function Model Order 🔲 in the top toolbar. This function allows you to select the transfer function order – Zero Order, First Order or Second Order. You can also select the sign of the process gain (positive or negative). Based on your knowledge of the process, chose the transfer function order. PITOPS-TFI automatically sets the process gain, dead time and time constant to some reasonable non-zero values as the initial guess.

This example is a second order transfer function with positive gain. So here, click on Transfer Function Model Order 🔲 in the top toolbar, click on Second Order, Positive Gain and then click Ok.

Step #6: Run Simulation

Click on Run / Simulate 🔲. Notice that the blue trend (in the topmost plot) which was a flat line before now is somewhat similar to the red trend. The blue trend is the prediction of the product purity based on the reflux flow input signal and the transfer function parameters.

The blue trend is also called Model Prediction. PITOPS reads the product purity, reflux flow data from the Excel file, the transfer function parameters and generates the model prediction.

Note the value of Error displayed near the right side of the screen. This is the difference between the blue and the red colored trends summed at every sample time (one minute in this case). If the blue and red signals were identical (superimposed on top of each other), then the Error would be zero.

Step #7: Analyze Transfer Function Parameters

Try different values of transfer function #1 parameters. For example, set Gain = 5 while keeping other parameters unchanged. Click on Run / Simulate 🔲. Notice that the blue colored trend expands significantly compared to the red. Obviously, we made the transfer function fit worse. Try different values for Delay, Gain, Tau1 and Tau2 to study the impact on the simulation.

Step #8: Identify Transfer Function

Re-set the initial guess to: Delay = 5, Gain = 2, Tau1 = 15 and Tau2 = 15. Click on Run / Simulate 🔲. Note the value of Error.

Click on Run / Identify or the icon 🔍 to trigger the transfer function parameter identifier (the identifier identifies the transfer function parameters). Near the bottom left corner of the screen, a message appears: ""**Identification in Progress, Please Wait…(Press Escape key to stop anytime)** "". After a short time, a message window pops up indicating successful identification. Click on OK.

The PITOPS-TFI identification algorithm searches for the best transfer function parameter fit based on their starting values entered earlier.

Notice the new and improved Transfer Function #1 parameters determined by the PITOPS-TFI identifier. The Error value is lower than the previous case.

Try different initial transfer function parameters and then click on Run / Identify 🔍 again. If the initial values are very far from the optimum values, then the identification algorithm may not be able to identify good transfer function parameters and you will see a "Fail" message. In this case, change the initial guessed values of transfer function parameters and click on Run / Identify 🔍 again.

After clicking on Run / Identify 🔍 , and after PITOPS has determined new (optimum) transfer function parameters, if you click Run / Identify 🔍 again, you will see a message "**Calculations Complete**". The Identify function will not re-run unless you change one or more of the transfer function parameters and then click on Identify again.

Notice that the blue colored trend (model prediction) in the top window now closely matches the product purity CV data (red colored trend).

The transfer function parameters: Delay = 11, Gain = 3.0 and Tau1 = 97 and Tau2 = 4 represent the process dynamics fairly well.

Step #9: Save Case File

Now we can save all identified transfer function parameters and the plant data filename to a case file for future re-runs and continued analysis, if necessary.

Click on File / Save As or click on the Save Case File icon 🖫. Enter any desired filename to save, with "TF" as filename extension (example, TEST2.TF). The "TF" filename extension is an abbreviation for "Transfer Function". Click on Save. Now a file with that name will be created. By saving the file, one can restore the complete example later conveniently.

A case file named EX2.TF has been provided with the PITOPS software. This is a case file with all configuration data from this example. To bring up this example, click on File / Open Case File or click on the icon 📂 and then select EX2.TF.

4.0   EXAMPLE #3 - IDENTIFY MULTIVARIABLE TRANSFER FUNCTIONS USING CLOSED-LOOP PLANT DATA

This example illustrates the simultaneous identification of three transfer functions. This example is based on a typical distillation column with one feed stream, one reboiler and one reflux stream. See Figure 5.

Figure 5. Multivariable Identification for Distillation Column
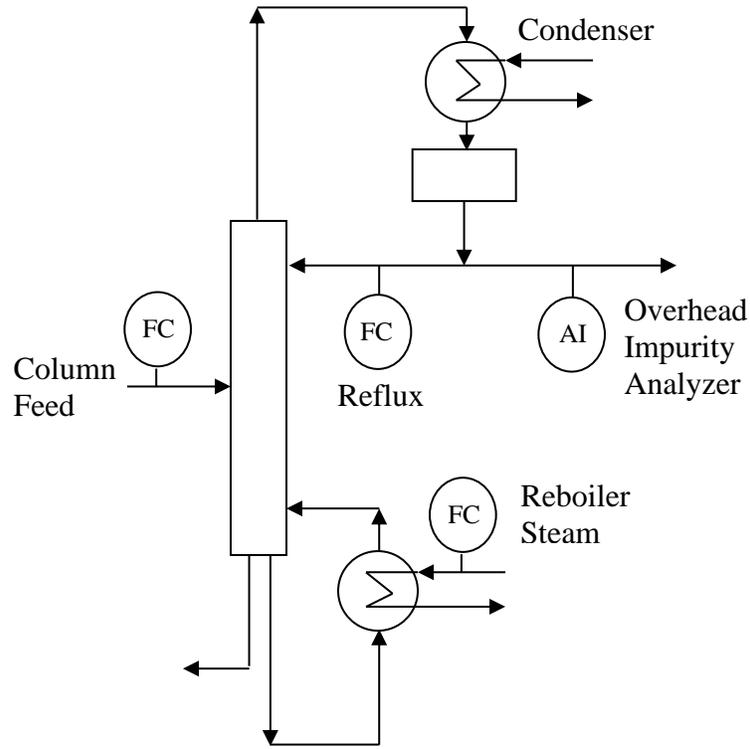
Transfer Functions
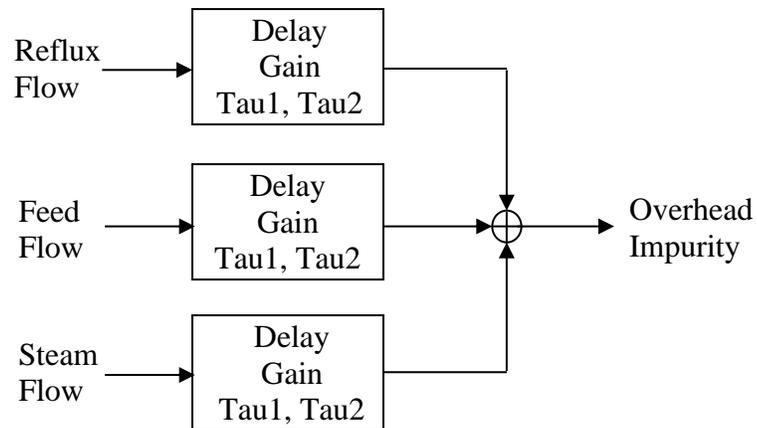
The process dynamics are such that if the reflux flow is increased then, the overhead product impurity decreases and vice versa. If either feed or reboiler flows are increased, the overhead product impurity increases.

This is a three-input example comprising of three independent transfer functions. The three transfer functions are:

- Reflux Flow to Overhead Product Impurity
- Feed Flow to Overhead Product Impurity
- Reboiler Steam Flow to Overhead Product Impurity

PITOPS identifies the three transfer functions simultaneously.

The reflux flow PID tagname is FC211, feed flow tagname is FC311 and the reboil steam flow tagname is FC411. The product impurity tagname is AI715.

The procedure for configuring PITOPS to identify the three transfer functions simultaneously is given below.

The Excel file named EX3 PLANT DATA.xls contains one-minute sampled data. This file is provided with the PITOPS-TFI software. The user can open this file and see the various columns containing the data for tags AI715, FC211, FC311 and FC411. The file data trends are shown in Figure 6.

Step #1: Plant Data Files

Examine the file EX3 PLANT DATA.xls. This file is created by the DCS data generating software at the plant. Sample time is one minute. The left-most column "Time" is required but the data in this column is not read by PITOPS-TFI.

Now start PITOPS-TFI by double-clicking on its icon.

Step #2: **Specify Filenames**

Click on File / New Case File or [icon] and click Yes. This erases data from any previous work prepares for a new case.

Click on File / Plant Data File or the icon [icon] and click on the file EX3 PLANT DATA.xls. Then click Open.

Near the top left corner of the screen, see label inside the box CV1: AI715. Click on this box and then you will see four choices – AI715, FC211, FC311 and FC411. By selecting AI715, then AI715 becomes the CV (Output) and by selecting FC211, then FC211 becomes the CV (Output). In this example, CV needs to be AI715, but this step demonstrates that you can make any column from the plant data file to be CV or MV. You can click on the boxes for MV1, MV2 and MV3 and change the variables. This is new for Version 8.1.

The topmost plot (red colored trend) displays the overhead product impurity data (CV). The second plot (also red colored trend) shows the reflux flow setpoint data (MV1). The third plot (also red colored trend) shows the feed flow setpoint data (MV2). The bottom-most plot shows

the reboiler steam flow setpoint data (MV3).

Note that the CV is also the *combined output* from the three transfer functions, as shown at the bottom of Figure 5. Also note that the three MVs are the three *Inputs* to their three respective transfer functions shown on right side of the screen.

Figure 6. Overhead Impurity versus Reflux, Feed and Steam
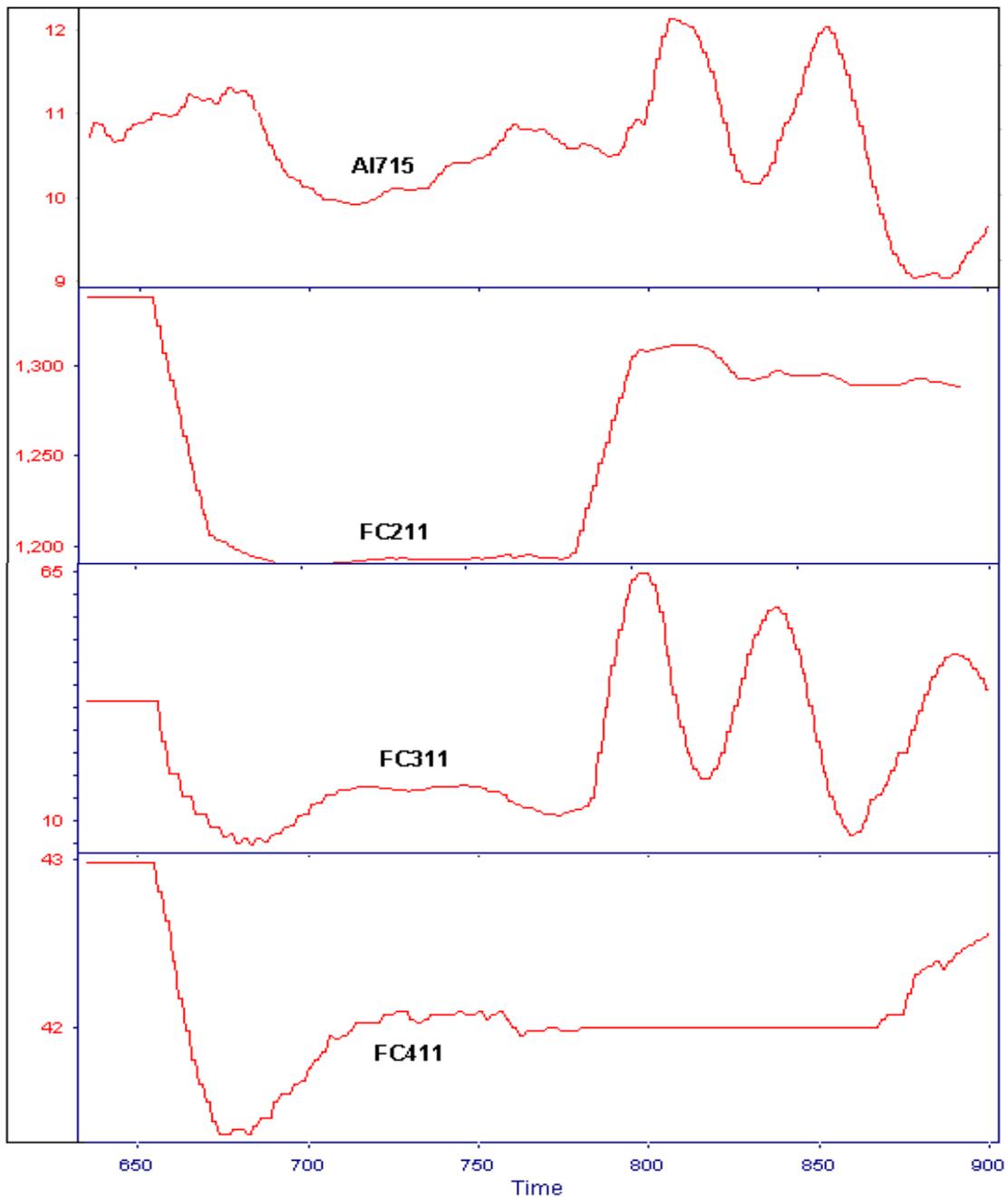
Step #3: Start Time, End Time and Sample Time

Portions of file data may be bad because of instrumentation problems, data collection errors or other reasons. To illustrate the problem, we will only use the good data in this example and ignore the rest of the data that are bad (unusable).

Notice that for MV2 (FC311), data are bad between time = 0 and 256. All four variables appear to be definitely good between time = 635 and 900.

Near the top of the screen, click on Start Time and set it to 635. Near the bottom of the screen, set End Time to 900. This means that we wish to analyze data only between time = 635 and time = 900. All other data (before 635 and after 900 are ignored).

Sample Time is 1 minute in this example because we know that the data in the plant data file are spaced apart at 1 minute time intervals.

Step #4: **Transfer Function Parameters**

Some approximate, initial values for transfer function parameters need to be specified. These may be determined by conducting plant tests or consulting experienced control room operators. These guesses need to be only approximate.

Initial guesses are provided below. Type in the following initial guesses for Transfer Function Parameters for the three transfer functions.

It is important that the *sign* of the gain (positive or negative) is correctly entered. From process knowledge, here we have to know that for TF #1, the gain is negative and for TF #2 and TF #3, the gains are positive.

TF Parameters	TF #1	TF #2	TF #3
Delay	2	2	2
Gain	-1.0	1.0	1.0
Tau1	25	25	25
Tau2	25	25	25

By setting Tau2 (Time Const. #2) to a non-zero number, PITOPS-TFI will identify a second order transfer function fit. If Tau2 is set to zero, then PITOPS-TFI will identify Tau1 (Time Const. #1) only.

Instead of setting the initial guess for transfer function parameters manually as explained above, PITOPS-TFI provides a convenient function to automatically set the initial transfer function parameters. To use this function, click on the icon for Transfer Function Model Order 🔲 in the top toolbar. This function allows you to select the transfer function order – Zero Order, First Order or Second Order. You can also select the sign of the process gain (positive or negative). Based on your knowledge of the process, chose the transfer function order. PITOPS-TFI automatically sets the process gain, dead time and time constant to some reasonable non-zero values as the initial guess.

This example is a second order transfer function with positive gain. So here, click on Transfer Function Model Order ⬚ in the top toolbar, click on Second Order, Positive Gain and then click Ok. Notice that PITOPS-TFI sets *all three* transfer function parameters as follows: Delay = 2, Gain = 1, Tau1 and Tau2 = 10. These are just some reasonable arbitrary initial values for the transfer function parameters. Based on our process knowledge we know that Gain of Transfer Function #1 is negative. Change the sign of Transfer Function #1 Gain from +1 to -1.

Click on the box on the far right of the screen that shows a +/- and this clicking toggles the gain of the transfer function from positive to negative. This is a new function for this version 8.1.

If you want to zero-out all transfer function parameters, then click on the box with a z inside and notice that all transfer function parameters are now zero. This is a new function for this version 8.1.

Step #5: **Run Simulation**

Click on Run / Simulate ⬚ to run the simulation. PITOPS reads the data from the EX3 PLANT DATA.xls file, the transfer function parameters and generates a model prediction, shown as the blue trend in the top window. The Error is shown on the right corner of the screen. This is the difference between the blue (transfer function predicted) and the red (actual product impurity) trends summed at every sample time of one minute.

Step #6: **Identify Transfer Function**

Note that the blue trend seen after clicking on Run / Simulate ⬚ icon is the combined prediction based on all three inputs (MV1, MV2 and MV3). If the model prediction (blue line) is almost superimposed on the red (CV), this is an indication of good transfer function parameters. With the initial guesses of transfer function parameters entered above, there is a significant difference between the model prediction (blue trend) and the product impurity (red trend).

PITOPS-TFI can identify improved transfer function parameters. The initial (guessed) transfer function parameters must be reasonably correct. If the initial parameters are very different from the actual ones, then PITOPS may not be able to determine improved parameters.

For example, if the actual dead time is 10 minutes, then values of 2-20 are reasonable starting guess; but guesses of 30 or more are poor. If the process gain is -1.0, then guesses of -0.1 to -10.0 are reasonable. If actual Tau1 or Tau2 are 30, then guesses of 5 to 100 are reasonable initial guesses.

The user should select initial guesses based on process and dynamics knowledge and then run the PITOPS simulation to check the prediction. The prediction should be at least directionally correct as seen in the plots (red and blue trends).

Make sure that the transfer function parameters are as specified in the table above. The Identify boxes must be checked for all parameters. This means that we want PITOPS to identify all parameters. If any box is unchecked, that parameter will be held fixed at the guessed value. All checked parameters will be changed while trying to search for an improved model prediction. Keep the Identify box for Valve Stiction *unchecked* and its value at the default value of *zero*.

Click on Run / Identify 🔍 . This step may take several seconds. During the identification,

PITOPS searches for the best fitting transfer function parameters. On completion, a success message box appears, indicating that new and improved transfer function parameters were determined. Click on OK. Observe the updated blue trend showing the new model prediction. Notice that the blue and the red trends are almost superimposed now, better than before. Note the improved transfer function parameters identified by PITOPS. The Error is reduced compared to before clicking the Run / Identify 🔍 button.

Different initial guesses may lead to a different final best set of identified transfer function parameters.

It is recommended that different guesses be tried followed by clicking the Run / Identify 🔍 button to explore possibly different results.

Knowledge of the process and user discretion must be used in selection of the final best set of transfer function parameters.

Step #7: **Select Trends**
Near the bottom right of the screen, you will see Select All and Unselect All. This example has three inputs (three MVs) and you have the option of selecting or unselecting the three MVs – FC211, FC311 and FC411. Keep all three checked to see all three MV trends. Uncheck one ore more if you do not want to see those trends.

Step #8: **Save Case File**

Now you can save all identified transfer function parameters and the plant data filename to a case file for future re-runs and continued analysis, if necessary.

Click on 💾 or File / Save As. Enter any desired filename to save, with "TF" as filename extension and then click on Save. Now a file with that name will be created. By saving the file, one can restore the complete example later conveniently.

A case file named EX3.TF has been provided with the PITOPS software. This is a case file with all configuration data from this example. To bring up this example, click on File / Open Case File or click on the icon 📂 and then select EX3.TF.

5.0   EXAMPLE #4 - IDENTIFY VALVE STICTION AND TRANSFER FUNCTIONS SIMULTANEOUSLY

Control valves can be defective and exhibit stiction problems. Valve Stiction is explained in Part C, Section 10 below. Please read that section before proceeding further below.

PITOPS-TFI provides a novel and revolutionary technique of identifying valve stiction using plant data. The data can be closed-loop, open-loop or a mixture of both. Up to three transfer functions can be identified simultaneously in addition to identifying control valve stiction. This example illustrates how to identify valve stiction using plant data.

Step #1: Open Case File

Click on File / New Case File or click on the icon ▣ and then click Yes inside the popup window. Now click on Open Case File 📂, select the file Ex4.tf, and click on Open (the file Ex4.tf is provided with PITOPS software). This example has two transfer functions. See initial guesses for transfer functions and valve stiction on right side of the screen.

For all new cases that you may develop on your own later, you must specify an initial guess for the transfer function parameters before clicking on the Identify 🔍 button. If a transfer function parameter is set to zero, then the Identify 🔍 function will leave it at zero. If Valve Stiction is set to zero, then the Identify 🔍 will not search for valve stiction and will leave it at zero. Click on Transfer Function Model Order 🅜 in the top toolbar to conveniently populate the initial guess for the transfer function parameters and then remember to change the sign (+ or -) of the transfer function gain to be correct, matching with the process. If you want the Identify 🔍 function to also identify the valve stiction, then you must specify a non-zero value for Valve Stiction.

Step #2: Examine Plant Data File

Click on Plant Data File 📄 ; you will see the Excel filename EX4 Plant Data.xls (this file is also supplied with PITOPS software). The MV1 and MV2 columns are the two inputs and the CV is the output. Note that this example data is from a simulation and are not real plant data.   The purpose of this exercise is to explain how to identify valve stiction and two transfer functions simultaneously using the supplied data.

Step #3: Understand Control Schematic

Figure 7 shows a control schematic. Stiction exists between the MV1 (Input1) signal and the input to the Transfer Function #1. The MV2 signal passes through the Transfer Function #2. The outputs from the two transfer functions are summed to comprise the CV signal. Note that the scope of this example is all inside the red envelope with all the red colored elements.

Now examine all the blue colored elements. Notice that the MV1 (Input1) could be the output from a PID and the CV (Output) signal could be the PV signal going to the PID. So, this could be a PID controller with valve stiction.

The MV2 signal could be a disturbance signal. However, our goal in this example is to make use of the MV1, MV2 and CV data and then identify simultaneously both transfer function parameters and valve stiction.

Step #4: Identify Stiction and Transfer Function Parameters

Note the initial transfer function parameters and the stiction value. Note that the initial value of Valve Stiction is 5. Now click on Identify 🔍 . PITOPS-TFI identifies all six parameters for both first order transfer functions and the valve stiction. Compare the values before and after clicking on Identify. Note that PITOPS-TFI changes the initial guessed value of Stiction from 5 to 14. Notice that the blue trend (transfer function model prediction) and the red trend (CV data from the Excel file) in the top window are completely superimposed on each other indicating a good fit.

For any reason, if you desire to restore the values of transfer function parameters and valve stiction to what they were before you clicked on Identify 🔍 , then click on the Restore button located near the top right corner of the screen. This is a nice feature if you want to run several "Identify" cases with one or more different values in the starting set.

Figure 7. Valve Stiction Identification
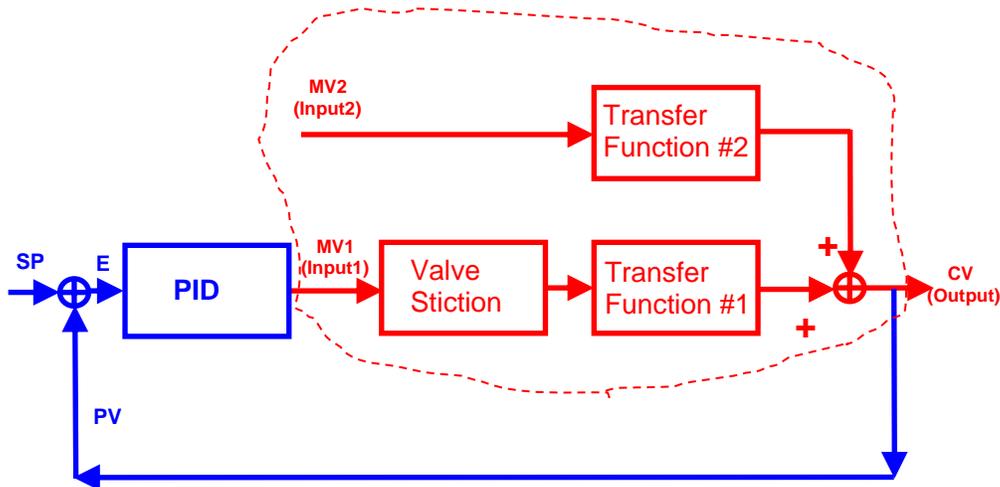
To use Restore, first input your starting set of transfer function parameters values and valve stiction. Then click on Identify 🔍 , and then note the results. Click on Restore and then change one or more values and click on Identify 🔍 again to compare results with different starting values of transfer function parameters and valve stiction. Use the Identify 🔍 and Restore functions conveniently to compare and study the results.

6.0   EXAMPLE #5 - IDENTIFY TRANSFER FUNCTIONS FROM STEP RESPONSE COEFFICIENTS

PITOPS-TFI can convert step response coefficients into equivalent transfer functions. Three examples in this section illustrate this feature.

Step #1: Study Format of Step Response Model File

Using Notepad or any text editor, open the file EX5.mdl (this file is supplied with the PITOPS software). The file contains vector coefficients characterizing the dynamic response due to a unit step change in the input signal. The input signal is not part of the file. Only the CV response data are shown. PITOPS-TFI reads the data starting with the first row, reading from left to right. When all data in the first row are completely read, then it proceeds to the second row and then the third, etc. till all columns are completely read.

Step #2: Identify Transfer Function

Click on File / New Case File or click on the icon ⬜ and then click Yes inside the popup window. This erases old data and prepares for a new case. Now click on Plant Data File 📄 .

Click on the select arrow next to Plant Data Files and select Step Response Files (*.mdl) located above Open and Cancel. Click on Ex5.mdl (this file is supplied with PITOPS) and click Open. Now file EX5.mdl is read. Click on "Identify"🔍 icon and PITOPS runs the identifier and generates transfer function parameters with the best fit for this dataset. Click OK to see the results of the identifier.

Now for practice, change the values for the transfer function parameters, start time, end time and identification method. Set Delay = 1, Gain = -1, Tau1 = 25 and Tau2 = 5 (some arbitrary but realistic transfer function parameters). Note that we set a negative sign for the gain because based on looking at the plots, a positive change in the MV causes the CV to go down. Note that the transfer function parameters must be set to non-zero before the "Identify"🔍 icon can be clicked.

Leave the Start Time and End Time to their existing values of 0 and 119. Leave the Identification Method at the default Geometric selection.

Now click on Identify 🔍 . Click OK when you see the "success" message. See the identified transfer function parameters on the right side of the screen. The bottom plot labeled "Input1 (MV1)" shows a unit step change. The red trend in the top window is the data from the Ex5.mdl file and the blue trend in the top window shows the transfer function prediction based on the identified transfer function parameters show on the right side of the screen.

We fitted a second order with delay transfer function above. But we could also try to fit a first order transfer function if we set Tau2 = 0 and then click on Identify 🔍 .

Instead of setting the transfer function parameters manually, you can also conveniently initialize the transfer functions by clicking on the 🅜(Transfer Function Model Order) and select Second Order, Negative Gain and then click on Identify 🔍 .

Based on examination of the CV, MV data (the red trends), you can estimate the delay time in

some cases and then the delay time can be set fixed at the estimated value by unchecking the Identify box next to the Delay time. Now if you click on Identify 🔍 , then PITOPS identifies the other transfer function parameters whose Identify boxes are checked while leaving the Delay time fixed. Similarly, if you feel you want to fix the transfer function Gain, then you can also uncheck the Identify box for the Gain and then have PITOPS identify the Tau1 and Tau2 parameters only.

Step #3: Fixing Known Parameters to Improve Transfer Function Fit

In most cases, one or more transfer function parameters are already well known. In such cases, you can fix the known parameters and allow PITOPS-TFI to identify the others. To illustrate this, continue from Step #2 above and click on Plant Data File 📄 . Make sure File Name type is Step Response Files (*.mdl) located above Open and Cancel. Click on Ex6.mdl (this file is supplied with PITOPS) and click Open. Now file EX6.mdl is read. Click on "Identify"🔍 icon and PITOPS runs the identifier and generates transfer function parameters with the best fit for this dataset. Click OK to see the results of the identifier.

Now, again for practice, change the values for the transfer function parameters, start time, end time and identification method. Set Delay = 1, Gain = -1, Tau1 = 25 and Tau2 = 25 (we specify some approximate, non-zero transfer function parameters). Note that we set a negative sign for the gain because based on looking at the plots, a positive change in the MV causes the CV to go down. Note that the transfer function parameters must be set to non-zero before the "Identify" 🔍 icon can be clicked.

Leave the Start Time and End Time to their existing values of 0 and 59. Leave the Identification Method at the default Geometric selection.

Now click on Identify 🔍 . Click OK when you see the "success" message.

Instead of setting the transfer function parameters manually, you can also conveniently initialize the transfer functions by clicking on the 🅜(Transfer Function Model Order) and select Second Order, Negative Gain and then click on Identify 🔍 .

Notice that this model has a small inverse response. To improve the fit, under Transfer Function #1, set Delay to 5.0 and **uncheck** the Identify box on the far right next to Delay. This fixes the Transfer Function #1 Delay Time to 5.0. Leave other Identify boxes for transfer function #1 checked. Based on the red trend in the top plot, we can visually see that only after time = 5.0, the red trend starts to really decrease. Click on Identify 🔍 . Notice now PITOPS-TFI generates a good fit with a second order transfer function model with delay set fixed at 5.0.

Step #4: Fitting a Zero Order Transfer Function

Now we will illustrate how to fit a zero-order transfer function to step response coefficients. Zero order is also called "ramp" or "integrating" type of transfer function.

Click on Plant Data File 📄 . Make sure File Name type is Step Response Files (*.mdl) located above Open and Cancel. Click on Ex7.mdl (this file is supplied with PITOPS) and click Open. Now file EX7.mdl is read.

To initialize transfer function parameters automatically to some starting values, click on the "Transfer Function Model Order" icon ⬛ and then click on Zero Order, Positive Gain and click on Ok.

Leave the Start Time and End Time to their existing values of 0 and 59. Leave the Identification Method at the default Geometric selection.

Now click on Identify 🔍 .

Click OK when you see the "success" message.

You can manually start the identification with a different initial set of transfer function parameters in order to conduct a "what-if" analysis. For practice, set Delay = 1, Gain = 1, Tau1 = 0 and Tau2 = 0 (we specify some approximate, non-zero transfer function parameters). Note that we set a positive sign for the gain because based on looking at the plots, a positive change in the MV causes the CV to increase. When both Tau1 and Tau2 are set to zero, this tells PITOPS to identify a zero-order (ramp or integrating type) transfer function.

Notice that this transfer function is a ramp (it does not reach steady state), but keeps ramping in response to the step change in the MV. A zero-order transfer function gain is also called the Ramp Rate. The ramp rate unit is calculated as CV unit / MV unit / Time. Note that the first-order and second-order gains do not have time in their engineering units, but the gain for a zero-order transfer function (ramp rate) does have time unit.

Now, in order to try to improve the fit, under Transfer Function #1, set Delay to 3 and *uncheck* the Identify box on the far right next to Delay. This fixes the Transfer Function #1 Delay to 3. Based on the red trend in the top plot, we can visually see that the time delay is about 3 time units. Leave Tau1 = 0 and Tau2 at 0. Click on Identify 🔍 . Notice now PITOPS-TFI identifies the ramp rate (zero-order transfer function) with delay set fixed at 3.

Note that the zero-order transfer function has only delay and gain (both Tau1 and Tau2 are zero). Many processes with very slow dynamics can be well characterized by zero order transfer functions.

You can click on the File / Save or Save As options or the 💾 icon to save all these cases for later use.

7.0   EXAMPLE #6 - IDENTIFY ZERO ORDER TRANSFER FUNCTION AMIDST DISTURBANCES

Real plant data often contains unmeasured disturbances, drift, nonlinearities and random noise from instrument signals. You may be trying to identify the transfer function between steam flow and some temperature. But as you raised the steam flow, a sudden rain storm cooled the temperature and reduced the real effect of your steam flow increase. There may not be an ambient temperature measurement and the effect of the rain becomes an unmeasured disturbance. Numerous cases like this one create unmeasured disturbances in the real plant.

Disturbances can make it difficult to identify transfer functions. If the disturbance effect is the dominant one, then the identified transfer function can be erroneous.

PITOPS-TFI has functionality to cancel-out the effect of unmeasured disturbances on the main transfer function (to-be-identified). This example shows how to use PITOPS-TFI to identify transfer functions amidst unmeasured disturbances.

Step #1: Read Plant Data File

Click on File / New Case File or click on the icon and then click Yes inside the popup window. Make sure File Name type is Plant Data Files (*.xlr, *.xls, *.xlsx) – this option is located above Open and Cancel.

Click on Plant Data File . Click on Ex8 Plant Data.xls (this file is supplied with PITOPS) and click Open.

The MV trend (bottom plot) shows two pulses. The CV trend (red trend in upper trend box) responds directionally reasonably until around time = 400 time units and then some disturbance comes in and causes the CV to keep rising even though the last MV change was at time = 300 time units.

Step #2: Specify Initial Transfer Function Parameters

Based on our process knowledge, we know this is a zero order (ramp) transfer function. Initialize the starting transfer function parameters by clicking on the Transfer Function Model Order icon and selecting Zero Order, Positive Gain. This initializes the transfer function parameters automatically to Delay = 2, Gain = 0.1, Tau1 = 0 and Tau2 = 0. Click OK to see the model prediction (blue trend). Make sure that the Identification Method is Geometric. Now click on Identify to improve the fit. The results from Identification are completely wrong and meaningless. Delay is fit to 542 time units (too high!). Examination of the CV (red trend) and the model (blue trend) in the top trend box explains the poor identification results: the unmeasured disturbance after time = 400 causes the model prediction to be completely erroneous and useless.

Step #3: Select the "Gravity" Identification Method

Click on Restore button to restore the Delay to 2 and Gain to 0.1. Now select Identification Method (located near top right corner of the screen) to Gravity. Select the 3G option under Plots, located also near top right corner of the screen. Now click on Identify .

Notice that the average slope of the Gravity signal (red trend) is fairly flat (constant) from time = 0 until about time = 325. And after that, there are some dynamics in the Gravity signal which indicates the presence of unmeasured disturbances.

Notice that the identification results are correct. The Delay is 11 and the Gain is 0.03 (Ramp Rate). These are correct values. Note that the use of Gravity Identification Method has successfully eliminated the effect of the disturbance after time = 325 and helped us to identify the correct zero order transfer function parameters.

For identifying zero order ramp type transfer functions, in case of plant data with disturbances and nonlinearities, use the Gravity Identification Method for better results. You may try the Geometric Identification Method first and then if the results are not good, try the Gravity Identification Method.

Click on the 3G option under Plots, located also near top right corner of the screen. Notice the Gravity signal trend window. When Identification Method selected is Gravity then areas with good fit will show a horizontal red trend (average slope of zero) inside the Gravity signal trend window. Where there is some model mismatch, the Gravity signal trend will show some dynamics (non-horizontal trend, non-zero average slope) indicative of the model error.

A case file named EX8.TF has been provided with the PITOPS software. This is a case file with all configuration data from this example. To bring up this example, click on File / Open Case File or click on the icon and then select EX8.TF.

8.0 EXAMPLE #7 - IDENTIFY FIRST & SECOND ORDER TRANSFER FUNCTION AMIDST DISTURBANCES

The previous example above explained how to identify zero order ramp transfer functions. Here, we will show how to identify a first order transfer function with time delay amidst disturbances and nonlinearities. This method can be applied to second order transfer functions also.

Step #1: Read Plant Data File

Click on File / New Case File or click on the icon and then click Yes inside the popup window.

Click on Plant Data File . Make sure that the option for File Name is Plant Data Files (*.xlr, *.xls, *.xlsx). Click on Ex9 Plant Data.xls (this file is supplied with PITOPS) and click Open.

The MV trend (bottom plot) shows a single pulse. The CV trend (red trend in upper trend box) responds correctly until time = 200 time units and then some unmeasured disturbance causes the CV to go down. So the CV response until time = 200 is good, but the CV change after time = 200 is not because of the MV step but because of the disturbance.

Now we will try to identify a first order transfer function between the MV and CV.

Step #2: Specify Initial Transfer Function Parameters

Set the Identification Method to Geometric. Initialize the starting transfer function parameters by clicking on the Transfer Function Model Order icon and selecting First Order, Positive Gain and click OK. This initializes the transfer function parameters automatically to Delay = 2, Gain = 0.1, Tau1 = 10 and Tau2 = 0. Click on Identify .

Notice that the final transfer function fit is a little skewed because of the disturbance effect after time = 200. Note the values of the transfer function parameters. The predicted transfer function gain of about 4.6 would have been higher had the disturbance not been present.

Step #3: Select the "Gradient" Identification Method

To combat the disturbance problem, set the Identification Method to Gradient. Click on the Restore button to re-set the Delay = 1, Gain = 1, Tau1 = 10 and Tau2 = 0. Click on Identify .

Notice that now, using the Gradient Method, the final transfer function fit is much better. The Gradient Method has nicely eliminated the disturbance effect. The transfer function identified here is much more accurate than when using the Geometric Method.

For identifying first and second order transfer functions, in case of plant data with disturbances and nonlinearities, use the Gradient Identification Method for better results. You may try the Geometric Identification Method first and then if the results are not good, try the Gradient Identification Method.

Click on the 3G option under Plots, located also near top right corner of the screen. Notice the Gradient trend window. When Identification Method selected is Gradient then areas with good fit will show a horizontal red trend (average slope of zero) inside the Gradient trend window. Where

there is some model mismatch, the Gradient trend will show some dynamics (non-horizontal trend, non-zero average slope) indicative of the model error.

Note that PITOPS-TFI does not require step or pulse tests, it can work with closed-loop data also. All three Identification Methods – Geometric, Gradient and Gravity can work with both open-loop and closed-loop data.

Remember that when there is significant level of spikiness, unmeasured disturbances and/or nonlinearities, then try Gradient method for first and second order transfer functions and try Gravity method for zero order (ramp) transfer functions.

A case file named EX9.TF has been provided with the PITOPS software. This is a case file with all configuration data from this example. To bring up this example, click on File / Open Case File or click on the icon [icon] and then select EX9.TF.

9.0   EXAMPLE #8- A COMPLEX CLOSED-LOOP EXAMPLE

The CV-MV process data from any plant can be superimposed with various levels of complex unknown and unmeasured disturbances.   Many plant DCSs and PLCs are equipped with plant data historians (data trending systems) that store several years of data. Instead of conducting new step tests on the SP or OP, you can literally go back months or years and select some windows of historical data for identification using PITOPS. The data could be any closed-loop or open-loop data during some normal process changes made by the operator during routine plant operation.

Note that though, for successful identification, there must be some cause-and-effect relationship in the data, like a setpoint change or ramp, or the closed-loop manipulation of the setpoints by some Cascade APC, MPC, supervisory system or some open-loop step tests. Just flat lines of setpoint, PV and output with some small random instrument noise are not useful and will produce meaningless transfer function parameters.

In this section we illustrate a rather complex example to illustrate the powerful capabilities of PITOPS-TFI. The MV-CV data here are from a mechanical extrusion device where pressure (CV) is controlled by adjusting feed rate (MV) to the device. There are numerous complex disturbances and the pressure controller is in Auto (closed-loop) mode.

Step #1: Read Plant Data File

Click on File / New Case File or click on the icon 🗋 and then click Yes inside the popup window.

Click on Plant Data File 📑 . Make sure that the option for File Name type is SIMCET Data Files (*.sim) – this option is located on top of Open and Cancel. Click on Ex10 Plant Data.sim (this file is supplied with PITOPS) and click Open.

Set Start Time = 3050 and End Time = 3200.

Make sure Plots point to MV-CV and Identification Method is Geometric.

Examine the CV/MV trends. A SP change was made from 63 to 61 at time = 3065 with the controller in Auto mode. The CV nicely goes down from 63 to about 61. Notice that the CV stays persistently above the new SP of 61 after time = 3125.

This is because an unmeasured disturbance creeps in and causes the CV to stay higher than the SP of 61. The controller responds by reducing the MV from 45 to below 41. Somewhere around time = 3100, the data are skewed because of the unmeasured disturbance. Without the disturbance, the CV would have settled at the new SP of 61 and the MV would have drawn a flat line around 45 or 44.5.

Now we will try to estimate the transfer function amidst the disturbance.

Step #2: Specify Initial Transfer Function Parameters

Initialize the transfer function parameters by clicking on 🖾 (Transfer Function Model Order) and select First Order, Positive Gain. This initializes the transfer function parameters to be: Delay = 2, Gain = 1, Tau1 = 10 and Tau2 = 0. If transfer functions #2 and #3 parameters are seen on the right side, zero out all transfer function #2 and #3 parameters by clicking on the box with a **z** inside.

Also uncheck their "Identify" boxes. Only transfer function #1 parameters must be set to Delay = 2, Gain = 1, Tau1 = 10 and Tau2 = 0.

Set Plots to the 3G option. Select Geometric method and examine the trends. Notice that with the Geometric identification method, the Gradient signal looks spiky and Gravity signal looks even spikier.

The Gradient and Gravity identification methods help to reject the effects of unmeasured disturbances, but their signals may look spiky. This spikiness in the Gradient and Gravity trends pose problems to the transfer function identification. The spikiness in the Gradient and Gravity signals can be dampened by using the Suppression factor (located near the top right corner of the 3G Plots window).   Use the Up and Down arrows next to Suppression near the top right area of the screen to adjust Suppression.

Step #3: Select the "Gravity" Identification Method

When we have high level of disturbances and with the controller in closed-loop mode, Gravity method is the best for first and second order transfer function identification.

Now set the Identification Method to Gravity. Toggle from Gravity to Geometric back and forth several times and compare how the Gravity signal becomes less spiky using the Gravity method and spikier using the Geometric method.

Step #4: Select the Suppression Factor

PITOPS-TFI provides suppression option on the CV data to reduce the harmful effects of signal spikes and improve the chances of getting good transfer function parameters. When using the Gravity method, PITOPS-TFI defaults the Suppression level automatically to High.

In this example, the CV signal is not very spiky and High Suppression makes the data appear too highly dampened. Click on the Suppression button displaying High and select Low.

Use the Up and Down arrows next to Suppression near the top right area of the screen to adjust Suppression.

Step #5: Study Identification Results

With identification method = Gravity and Suppression = Low, click on click on Identify 🔍 . PITOPS now calculates the transfer function parameters while rejecting the unmeasured disturbance. The Geometric signal is the residual signal (this is the unmeasured disturbance, also called the model error). PITOPS-TFI identifies and isolates the unmeasured disturbance accurately. The transfer function parameters displayed on the right side of the screen show the true process dynamics after identifying, isolating and rejecting the unmeasured disturbance. This capability of isolating the residual disturbance and allowing the accurate calculation of the real transfer function is a unique and powerful distinguishing function of PITOPS that is not found in any other software product or technology. Examine the Gradient signal and Gravity signal trends. Flat Gradient and Gravity trends mean there are few or no unmeasured disturbances or nonlinearities. Movement and dynamics in Gradient and Gravity trends indicate portions of the data with some model mismatch caused by unmeasured disturbances and nonlinearities.

Compare the Output CV (red trend) and Model Prediction (blue trend) in the top-most plot. These trends show the raw CV and the transfer function model. Notice that the fit is very good until around time = 3100 and then the effect of the unmeasured disturbance causes the CV and model to diverge apart. The Geometric signal shows the error between the raw CV and the model prediction.

Had we used the Geometric method here, or even the Gradient method, the impact of the unmeasured disturbance would have made transfer function parameter identification difficult and the identified transfer function parameters not so accurate. But the Gravity method successfully identified the transfer function parameters with good accuracy, despite the disturbances.

A case file named EX10.TF has been provided with the PITOPS software. This is a case file with all the starting configuration data for this example. To bring up this example, click on File / Open Case File or click on the icon and then select EX10.TF.

10.0   GUIDELINES FOR SUCCESSFUL IDENTIFICATION

Guidelines on how to successfully identify the correct transfer function parameters are given below.

These guidelines will help the user in achieving successful results with PITOPS and also clarify some common questions.

1.   **Need for Cause-and-Effect Relationship between MV and CV**

The plant data used for transfer function identification must contain some dynamic information in order to be useful. 0041fter reading in Excel file data, examine the PV and OP. Does PV change in the correct direction in response to change in the OP? E.g., if more steam, does temperature increase? If temperature decreases with more steam, then data are garbage, get new data. The window of data used in PITOPS must be carefully selected. The data must contain some meaningful MV-CV dynamic information. This means that MV changes must cause CV changes in order to have useful plant data. Data where unknown disturbances first caused the CV to deviate followed by feedback corrective action by the MV are useless and will result in bad (wrong) transfer function parameters).

2.   **Closed-loop Data or Open-loop Data**

With open-loop tests, primary PID setpoints are changed (pulsed up and down) based on a recommended move plan. Where ever possible, open-loop tests should be conducted.

However, if an existing advanced control strategy is manipulating the primary PID setpoints, these data can also be used for transfer function identification. Such data are called closed-loop data. Examples #1 and #2 described above (PITOPS-TFI case files- EX1.TF and EX2.TF) are based on open-loop data and example #3 (case file EX3.TF) is based on closed-loop data. Notice the box type pulses for input variables in examples #1 and 2 (characteristic of open-loop tests- EX1.TF and EX2.TF). Input signals in example #3 (EX3.TF) are not "clean" pulses, but were moved by an advanced control system, which was adjusting their setpoints every minute.

PITOPS-TFI can identify transfer function parameters successfully using any of the three cases:

- Open-loop data
- Closed-loop data
- Mixture of both Open-loop and Closed-loop data

In all cases, it is important that the process is at steady state at the start time of the data window.

Closed-loop data are not useful if the inputs were changed by the advanced control system or a human being in response to an unknown or unmeasured disturbance. This concept is illustrated in Figure 8.

The MV increase near the left causes a noticeable CV increase (inside the region marked

"**Good Data**"). Here there is a distinct cause-and-effect relationship. The increase in MV causes the increase in CV with some noticeable dynamics (delay and time constant). This action may be achieved by a setpoint change on the CV with an advanced control system.

However, inside the region marked "**Bad Data**", an unknown disturbance causes a dip in the CV. The control system responds by increasing the MV, but this is not a cause-and-effect relationship.

The MV responds to an unknown disturbance and in this case, there is not enough information to identify dynamics from the "bad" section. Such data windows must not be used for identification of the transfer function.

Figure 8. Good and Bad Data
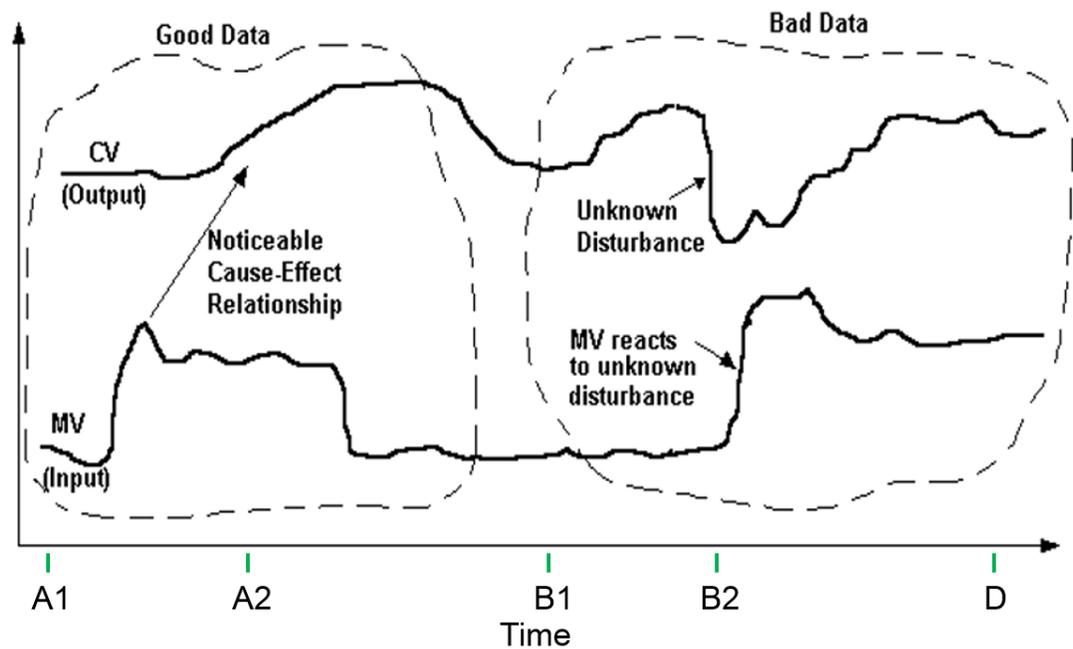
A summary of analysis of the MV and CV data in trend in Figure 8 is provided below:

- Time window A1 – B1 is good as there are two nice changes in MV that meaningfully impact the CV in response to both MV changes.
- Time window A2 – B1 is incorrect because the effect of MV change happening between time window A1 – A2 is ignored.
- Time window A1 – D may be used but Gradient or Gravity options will be required to reject the impact of unmeasured and unknown disturbance that comes just before B2. There will more uncertainty in this case A1 – D compared to the cleaner and best time window A1 – B1.
- Time window B2 – D is rather risky and not recommended. Partially meaningful results are possible with Gradient and Gravity options but the fact that a strong dip in CV occurs before the start time here (B2), there is room for uncertainty and erroneous results.

3.   **Start Time**

Select Start Time to be when both PV and OP are as stable as possible. This means process was stable and in equilibrium at start time and then the step changes generate accurate response. If there is a lot of movement in PV and OP before start time, then the unfinished effect of the past moves is unknown to the model fitting algorithm and could produce wrong transfer function parameters.

4.   **Model Order and Transfer Function Parameters**

Before clicking on Run / Identify 🔍 , the transfer function parameters must be initialized. The initialization procedure is quick and simple and is explained below:

Most industrial transfer functions can be characterized by three types:

- Zero order
- First order
- Second order

A zero-order transfer function consists of process gain (also called transfer function gain) and the process dead time.

A first order transfer function consists of process gain (also called transfer function gain), the process dead time and one time constant.

A second order transfer function consists of process gain (also called transfer function gain), the process dead time and also two time constants.

Before triggering the PITOPS-TFI transfer function parameter identification algorithm, you must specify the model order and must also specify an initial guess for all the transfer function parameters.

This is easy to do – click on 🅜 (icon for transfer function model order) and select one of the three options (Zero Order, First Order or Second Order) based on engineering knowledge of the process.

Then, select either Positive Gain or Negative Gain (the sign of the gain of the transfer function to be identified). Choose Positive if when OP increases then PV increases and choose Negative if PV decreases when OP increases. Now, PITOPS automatically initializes the transfer function parameters appropriately based on the selected model order and the sign.

Another way to initialize the transfer function parameters is to manually type in values for all the transfer function parameters on the right side of the screen under Transfer Function Parameters.

Consult with the plant operators or engineers to become familiar with the process. Based on process and dynamics knowledge, it is fairly easy to estimate the initial (approximate) values of transfer function parameters.

For example, if the real dead time in a process is 10 minutes, an initial estimate of 1 to 15 minutes is a good initial guess. Similarly, if the real process gain is 5.0, then initial guesses of 0.1 to 10 are good starts. Similar guidelines apply to time constants.

If good initial estimates are not available, then various different values can be tried and the simulation plots examined to help determining good guesses. If initial guesses are very poor (too far from the correct values), then PITOPS may not always be able to determine improved parameters.

As a start, use the ⬛ (Transfer Function Model Order) icon to initialize the transfer function parameters. This works well in most cases and is simple.

4.   **Number of Input Signals**

Most chemical and industrial processes are accompanied with noise, unknown disturbances and some nonlinearities. Also, it is often difficult to conduct long duration open-loop plant tests.

PITOPS is designed to identify transfer function parameters with short duration data. Uncertainty in the accuracy of identification is high if there are many changing input signals.

Experience has shown that dynamics identification with short duration real plant data with more than three inputs leads to some uncertainty in the final transfer function parameters. Different sets of transfer function parameters may appear to fit the data almost equally well.

PITOPS is designed to work with a maximum of three inputs and the longest time window of 50,000 time units.

5.   **Identify Check Box**

In addition to specifying the initial transfer function parameters, the Identify check box must be either checked or unchecked for each transfer function parameter. The Identify check box is located near the right side of the screen. The purpose of this option is to allow the user to fix certain parameters if they are already accurately known.

For example, if the delay is known to be definitely 10 minutes, the user can enter 10 for dead time and uncheck the Identify box for delay. In this case, PITOPS will set the delay fixed at 10 minutes while searching for other parameters (gain and time constants). One or more parameters can be unchecked (set constant), if the user is certain about their accurate values.

By fixing known parameters, uncertainty of the problem can be further reduced thereby increasing the chances of accurately determining other unknown parameters.

If you already know one or more transfer function parameters correctly then you could set them constant by unchecking their Identify box(es) and this can help to correctly identify the other transfer function parameters.

6. **Setting Some Parameters to Zero**

If a transfer function parameter is set to zero, it will be left fixed at zero by PITOPS. The Run / Identify 🔍 function will not change the value from zero.

At least one of the transfer function Gain values must be non-zero before clicking on the Run / Identify 🔍 function. If all gains are zero, then PITOPS will request you to set some reasonable values for the transfer function parameters before clicking on Run / Identify 🔍 .

If you need to set all transfer function parameters to zero, then click on the box with a small **z** inside. This is a new function in PITOPS 8.1 version.

Normally there is timestamp, PV, SP and OP in data file, or the order of columns can be timestamp, PV, OP and then SP. Note that SP data trends from Excel file are only for reference when looking at the PITOPS screen but the SP does not explicitly come into the calculations. If SP is in the third column, then click on the "**z**" to set all transfer function parameters for transfer function #1 to zero since we are only identifying transfer function between OP and PV. If SP is in the fourth column, then click on the "**z**" to set all transfer function parameters for transfer function #2 to be zero since we are only identifying transfer function between OP and PV. Now you can press F6 (identify, same as click on magnifying glass 🔍).

7. **Dynamics of the Primary Control Loop**

It is important to remember that in case of cascade loops, the slave loop dynamics are a part of the cascade transfer function.

Consider the example where a temperature PID (TC) is manipulating the setpoint of a steam flow PID (FC) to control a temperature. The MV is steam flow and the CV is temperature. This is a cascade loop (TC is master and FC is slave). See Figure 9.

It is important to optimally tune the slave loops first before attempting to identify the master loop dynamics.

In the above case, the FC needs to be tuned first optimally. Then, the dynamics between the FC setpoint and the temperature (CV) need to be identified. Note that in this case, the MV is really the FC **setpoint** and **not the actual flow**. The data read by PITOPS will be for temperature (CV) and for the steam FC setpoint.

If the FC is tuned optimally first before conducting any pulse tests on the FC setpoint, then the flow dynamics will be included in the transfer function between temperature and FC setpoint. If the FC tuning is too slow, this will increase the dead time and time constant for the temperature also.

Figure 9. Cascade PID with Fast Slave Dynamics
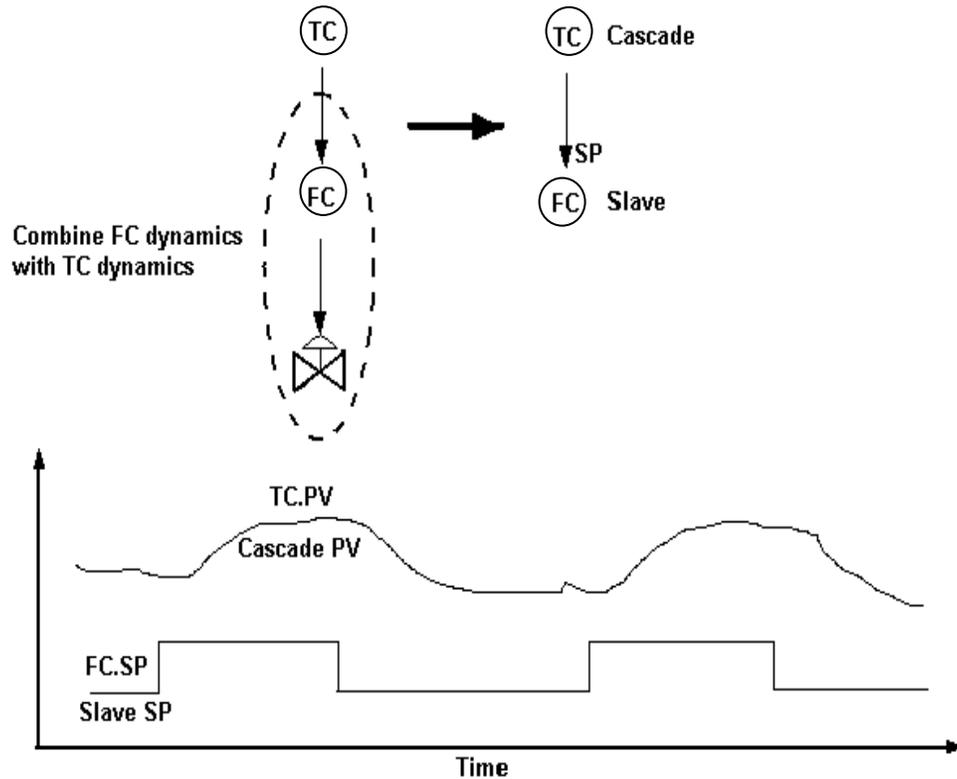
8.   **Significant Unmeasured Disturbances**

Industrial data are often complicated by unmeasured disturbances.

For example, consider a transfer function between a steam flow control valve and temperature in a reactor. The steam flow control valve is stepped up from (say) 50% to 55%. The temperature rises (as expected) from initial value of 150°C and settles to a new steady state of 160°C. A sudden rain storm causes the ambient temperature to drop significantly. This causes the reactor temperature to drop from 160°C to 157°C.

Identification of the transfer function parameters using only the steam-valve and reactor temperature data (without incorporating the ambient temperature as the second input) will show incorrectly lower transfer function process gain caused by the drop in ambient temperature.

If the above case is setup as a two-input case, with input #1 as the steam-valve and input #2 as the ambient temperature, then PITOPS-TFI can identify both transfer functions- first from steam to reactor temperature and the second from ambient temperature to reactor temperature.

If the ambient temperature signal is not available in the DCS, PLC or the control system, then it will be an unmeasured disturbance.

For first and second order transfer function processes, with significant unmeasured disturbances, use the Gradient or Gravity options for transfer function identification. This option can be seen under Identification Method on the main screen.

For zero order transfer function processes, with significant unmeasured disturbances, use the Gravity option for transfer function identification. This option can also be seen under Identification Method on the main screen.

If there are significant unmeasured disturbances, the Geometric method may not work well. In these cases, Gradient and Gravity options will produce better results.

The selection of the correct level of Suppression is important. The Suppression factor can be seen on the 3G window. If using the Gradient method, then increase Suppression if the red Gradient trend is too spiky and reduce Suppression if it is too smooth. If using the Gravity method, then increase Suppression if the red Gravity trend is too spiky and reduce the Suppression if it is too smooth. Suppression can be adjusted using the up and down arrows.

Summary of how to use the options Geometric, Gradient and Gravity:

    a. If data are clean and there are not many unmeasured disturbances, then use Geometric option before clicking Identify (clicking on magnifying glass or pressing F6 are same).
    b. If there are strong unmeasured disturbances, then use Gradient for first and second order transfer functions and Gravity for zero order transfer functions.
    c. If you chose Gradient or Gravity, then adjust the Suppression so that the gradient and gravity trends are not spiky and not overly smooth.

9.   The "*Railway Line*" Concept

Observe the red trend (raw CV) and blue trend (model prediction) for the raw data on the MV-CV screen. If the blue and red trends are superimposed, this is a sign of successful identification. Unknown and unmeasured disturbances are often present and may cause a vertical shift in the Y axis and then if you see constant deviation between red and blue trends (railway lines or parallel lines), then this is also a sign of good models. If red and blue trends are parallel but deviating, this is OK.

10.   Manual Adjustment of Transfer Function Parameters

If you are having some difficulty identifying transfer functions due to disturbances or unknown problems, then you can change the transfer function parameters manually, based on a good guess or knowledge based on process conditions and then click on magnifying glass again (Run / Identify 🔍 function). Check the Error value, if this value is lower then, you have a better model (better transfer function).

11.   Manual Adjustment of Dead Time

Sometimes increasing or decreasing the dead time does not have a major impact on the

model error, then manually set the dead time based on watching the peaks of the red and blue trends. If the blue trend peaks before the red trend, then reduce the dead time and vice versa. Sometimes, fixing the dead time based on prior knowledge based on some data examination may help to get a better set of transfer function parameters.

12.   Restore Function

After clicking on Run / Identify 🔍 function to identify transfer function parameters, if you do not like the new results (new transfer function parameters), click on the Restore button located near the top right area of the main screen. Try different new values of the transfer function parameters and press F6 again or click on Run / Identify 🔍 to identify. Now you may be closer to a better local minimum and may get better transfer function parameters.

13.   Good Fit but Bad Models

Remember that if you have crisp step tests, then the transfer function model parameters are easy to identify because the steps produce good excitation between the MV and the CV. In contrast, if you have gradual changes in the MV signal and no step tests, then multiple transfer function parameters may look good and make the blue model trend superimpose on the red raw trend. The blue trend model prediction from a transfer function with higher dead time and shorter time constant may look similar to another transfer function with shorter dead time and longer time constant. In this case, you need to apply some engineering judgement and process knowledge and fix some known parameters.

14.   Data Compression and Data Filtering

Make sure that there is no data compression and no excessive data filtering on all the data read into PITOPS TFI. Data compression will result in wrong transfer function calculations, especially for zero order transfer functions. Ask your system engineers to turn off data compression and any data massaging before collecting data for PITOPS.

11.0   CONFIRMATION OF SUCCESSFUL IDENTIFICATION

This section describes how to confirm whether the identified transfer functions are meaningful and correct. In other words, are the identified transfer function parameters correct and meaningful?

Data distorted with unmeasured or unknown disturbances, high random noise, too short data duration used for identification are a few of the many reasons transfer function identification may not be successful.

1.   **Examination of Trend Plots**

If the blue (model prediction trend) is almost superimposed on the red (CV plant data) trend, then this is a good sign. The transfer function parameters are likely to be correct.

Note that with industrial process data, it is almost impossible for the prediction trends and the actual CV trends to completely superimpose on top of each other. Noise and disturbances are always present in real industrial data, so some periods of mismatch between the model prediction and the actual CV cannot be avoided. But if over 75% of the data window shows the model prediction trends and the actual CV trends matching well, then this is satisfactory.

On the 3G Plots screen, if the Gradient and Gravity trends are more or less a flat (horizontal) line, then this is also an indication that the identified transfer function parameters are correct. The Gradient and Gravity trends may appear spiky. In this case, click on the box next to Suppression and increase the Suppression. This will make the Gradient and Gravity trends smoother and then visually inspect the trends to see if they are a flat (horizontal) line.

On the 3G Plots screen, if the Residuals trends are more or less a flat (horizontal) line with an average value zero, this this is also a good indication that the transfer function parameters identified are correct.

2.   **Process Knowledge**

Most experienced operators and engineers are knowledgeable about the dynamics of the process. They will have the knowledge that the dead time is likely to be between 1 second and 25 seconds but they can vouch that the dead time cannot be zero and it cannot be more than 60 seconds on a process with which they are very familiar. It is a good idea to get such information from experienced plant personnel. So after the transfer function identification results from PITOPS, you can make sure that the PITOPS transfer functions match with the process dynamics knowledge of plant and process experts. If the transfer function parameters from PITOPS come out to be radically different, then set all the transfer function parameters with the approximate (best-guess) values from the plant experts and then click on the 🔍 "Identify" button. If the results continue to show significant mismatch, then change the initial values of the transfer function parameters again a few times and then click on the 🔍 "Identify" button again. If after various attempts, if there is still mismatch, then try to use a different data set.

This completes your training on the use of PITOPS-TFI. Part C serves as reference manual, describing each and every field on the screen and all menu options.