

USER MANUAL

PITOPS™ PLUS TFI
VERSION 1.1

**PROCESS IDENTIFICATION &
CONTROLLER TUNING OPTIMIZER SIMULATOR**

TFI
(TRANSFER FUNCTION IDENTIFICATION)

**INDUSTRIAL PROCESS CONTROL SOFTWARE
FOR DCS/PLC PID TUNING AND ADVANCED
PROCESS CONTROL DESIGN & OPTIMIZATION**

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PART A: **SOFTWARE INSTALLATION AND GETTING STARTED**

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PART A: SOFTWARE INSTALLATION AND GETTING STARTED

1.0 INTRODUCTION

Part A specifies the hardware required to run Pitops Plus software. It also explains software installation procedure and how to start and use Pitops Plus.

2.0 SOFTWARE REQUIREMENTS AND INSTALLATION

Pitops Plus runs on Windows XP, NT, Vista and other Windows operating systems. Microsoft® Excel software is essential for running Pitops Plus.

To install Pitops Plus, download program installation setup exe file from the piconcontrolsolutions website (www.piconcontrolsolutions.com).

To start installation, double-click PitopsPlus_Setup.exe file. To complete installation, follow all the step-by-step installation instructions on the screen. All Pitops Plus files will be installed to the specified program folder. A program Group "PITOPS-Plus" will be created with program icons "PitopsPlus", "PitopsPlus TFI Help", "PitopsPlus PID Help", "Readme First" and "License Agreement".

3.0 SIMPLICITY OF PITOPS™ AND RELATED PRODUCTS

Pitops™ is very simple to use for any plant operator, control engineer, DCS/PLC technician or researcher. Pitops™ works entirely in the time-domain (seconds, minutes, etc.) It does not use the more complicated "s" (Laplace) or the "Z" (discrete) domains.

Use of Pitops™ does not require deep academic knowledge of process control theory. This manual does not cover details of process control theory and fundamentals. For mastering process control theory and fundamentals, please see PiControl's Process Control CBT (computer-based training) module. This CBT is rich with powerful ideas and concepts on practical process control designed for the control room environment.

You are also referred to Simcet™, Apromon™ and Tadpole™ products, all designed to help you improve process control at your plant in many new and innovative ways.

Simcet™ is a real-time dynamic simulator that provides a real-plant like PID tuning environment. It lets you practice PID tuning and then take online real-time tests to test your PID tuning skills.

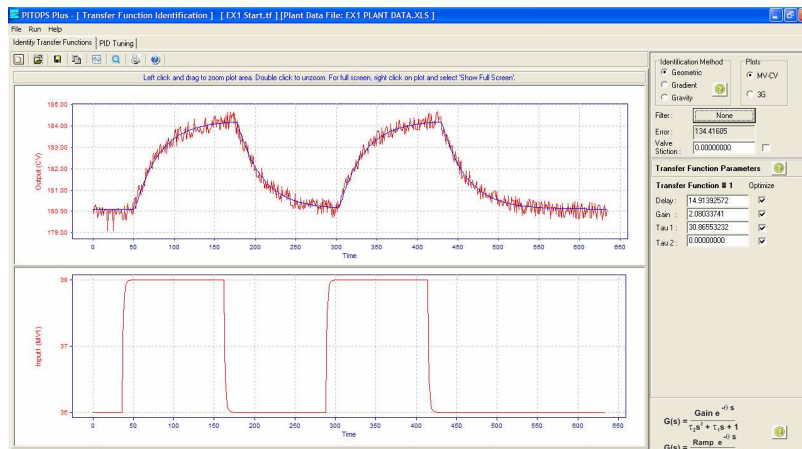
Apromon™ is a PID/advanced controller health monitoring and diagnostics software that helps to identify poorly performing controllers and then provides a structured methodology to improve the controller performance.

Tadpole™ is equipped with revolutionary, novel mathematics to reliably detect process oscillations and provide adaptive control.

For more information on all these products, visit the website www.picontrolsolutions.com.

4.0 MAIN SCREEN

Throughout this user manual, at various places, we refer to "**main screen**". The main screen is the main Pitops Plus TFI screen that you see when you start and use Pitops. The main screen is shown below.



5.0 GETTING STARTED ON USING TFI MODULE OF PITOPS

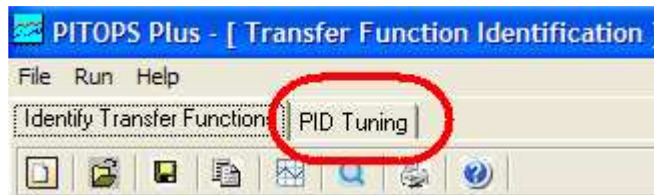
Pitops Plus software consists of two fully integrated modules- Pitops-TFI and Pitops-PID. After starting Pitops Plus, the TFI module is automatically started first. To go to the PID module, click on the PID Tuning tab as shown below. And then, to run the TFI module again, click on the Identify Transfer Function tab, also as shown below. Both these tabs are located near the top left corner of the Pitops Plus screen.

TFI stands for *Transfer Function Identification*. TFI module identifies transfer functions using time-series plant data. This document covers the TFI module only. Another separate document covers the PID module.

To start Pitops Plus, double-click on its icon (Pitops Plus). After start-up, an initial information screen is displayed, showing product and registration information. This screen is cleared after a few seconds.

Now continue to Part B of this manual for step-by-step procedures on how to use Pitops-TFI software. The skills and knowledge you will gain by going through Part B will prepare you for working with plant data from your own plant and then you can identify transfer functions on your own.

After identifying transfer functions, you can proceed to the PID software module of Pitops Plus by clicking on the PID Tuning tab located near the top left corner of the screen, as shown below:



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

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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.

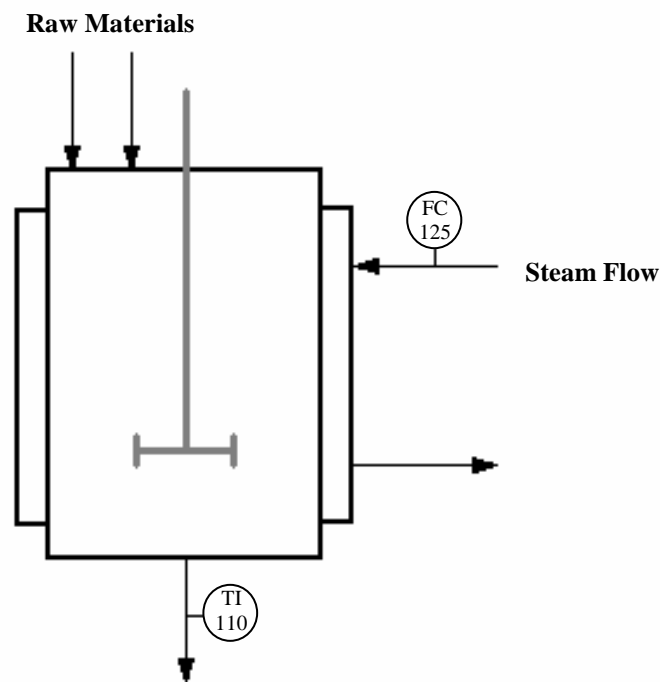
We want to identify the transfer function between steam flow and temperature based on trend data on these two variables. The tagname of the steam flow PID in the DCS or PLC is FC125 and the tagname for the temperature is TI110.

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



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.

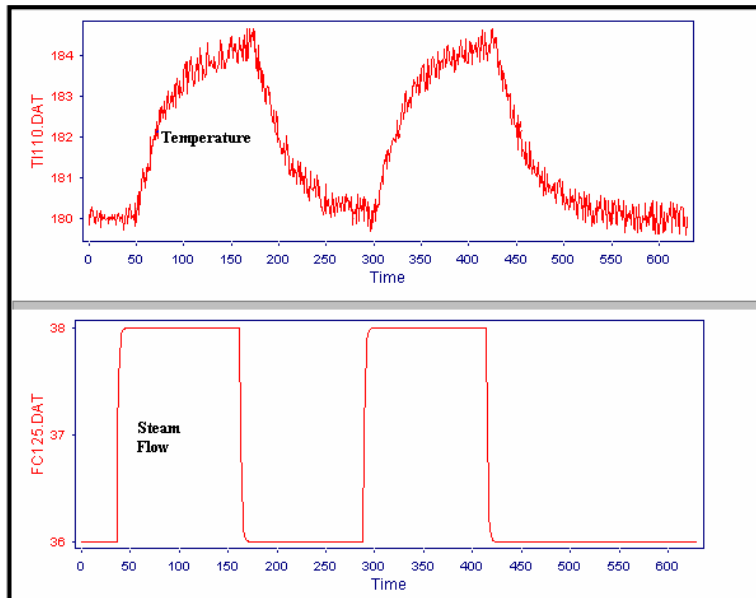
The first row contains tagname labels. The second and third rows in this file are intentionally left blank but they can be used to specify tagname descriptors and engineering units (these two rows are optional and may be left blank). This file format

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.

Figure 2. Steam versus Temperature Data




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 20000.

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 small box with three dots under Select Plant Data File. Select EX1 PLANT DATA.xls. Click on Read Data File; click Close.

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.

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

At the bottom 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: Transfer Function Parameters

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. Zooming like this helps to visually estimate the process dead time (time delay). Based on visual inspection, 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.


Step #5: 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 bottom right corner 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 #6: Check Guessed 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 and Tau1 and study the impact on the simulation.

Step #7: Identify Transfer Function

Re-set the initial guess to: Delay = 5, Gain = 1.5, Tau1 = 20. Click on Run / Simulate . Note the value of Error near the bottom right corner of the screen.



Click on Run / Identify or the icon  to trigger the optimizer (the optimizer identifies the transfer function parameters). Near the bottom left corner of the screen, a message appears: "*Optimization in progress, please wait*". After a short time, a message window pops up indicating successful identification. Click on OK.

Notice the new and improved Transfer Function #1 parameters determined by the Pitops-TFI optimizer. The Error 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 optimizer 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 Run / Identify  again. The identification algorithm may converge to slightly different values based on convergence tolerance. 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.

Step #8: 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 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.

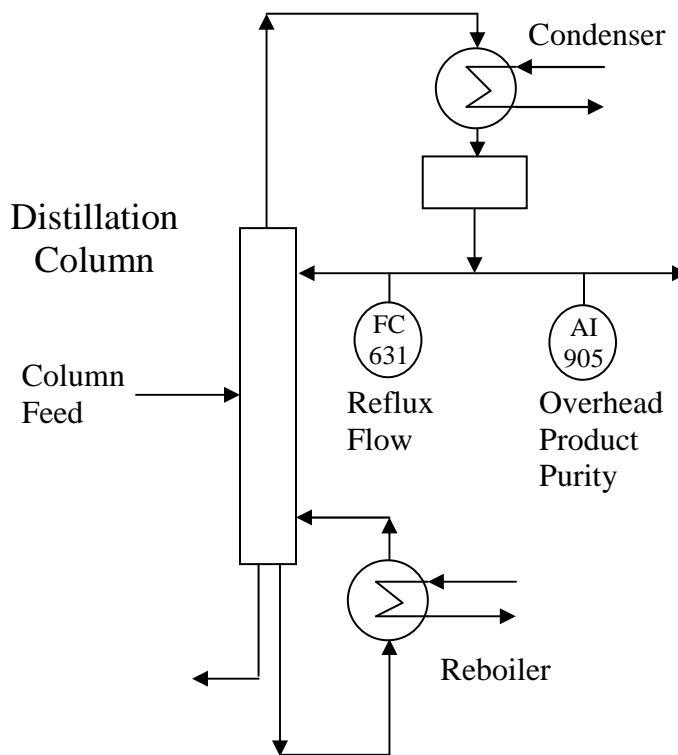
A case file named EX1.TF has been provided with the Pitops software. This is a case file with all configuration data from this example. To bring up this example, click on File / Open Case File or click on the icon  and then select EX1.TF.

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.

Figure 3. Reflux versus Overhead Purity Data



The DCS or PLC data extraction software needs to create an Excel file EX2 PLANT DATA.xls. 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 EX2 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:

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 20000.

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


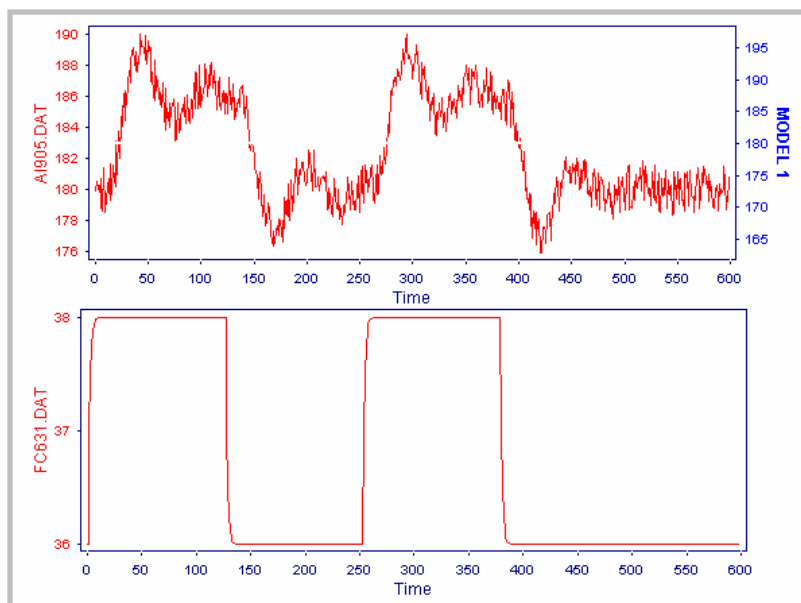

Click on File / New Case File or click on the icon  and then click Yes inside the popup window. This erases data from any previous work prepares for a new case.

Figure 4. Reflux versus Product Purity Data



Click on File / Plant Data File or the icon  and click on the small box with three dots under Select Plant Data File. Select EX2 PLANT DATA.xls. Then click on Read Data File; click Close.

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.

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

At the bottom 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: Transfer Function Parameters

Pitops-TFI provides powerful zooming feature. With left mouse, click in the topmost plot window somewhere around time = 0 and product purity (CV) = 184. Keep the left mouse key pressed and draw a rectangle towards the second coordinate close to time = about 40 and product purity (CV) about 178 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. Zooming like this helps to visually estimate the process dead time (time delay). 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. 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.

Step #5: 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 located near the bottom right corner 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 #6: 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 #7: 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 optimizer (the optimizer identifies the transfer function parameters). Near the bottom left corner of the screen, a message appears: "*Optimization in progress, please wait*". 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 optimizer. 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 #8: 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. 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.

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.

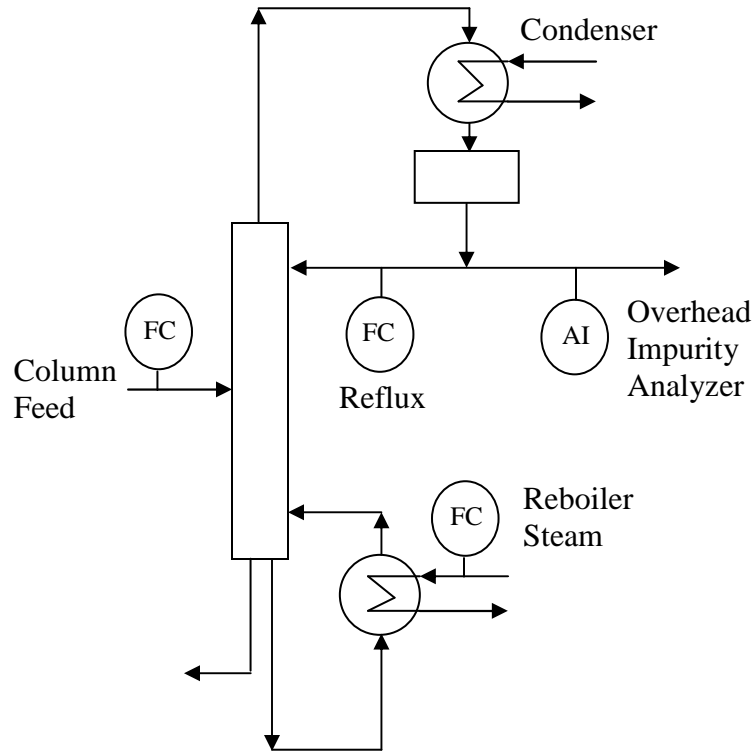
The Excel file named EX3 PLANT DATA.xls contains one-minute sampled data. This file is provided with the Pitops-TFI software. The user can open this file and see the various columns containing the data for tags AI715, FC211, FC311 and FC411. The file data trends are shown in Figure 6.

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.

Figure 5. Multivariable Identification for Distillation Column



Transfer Functions

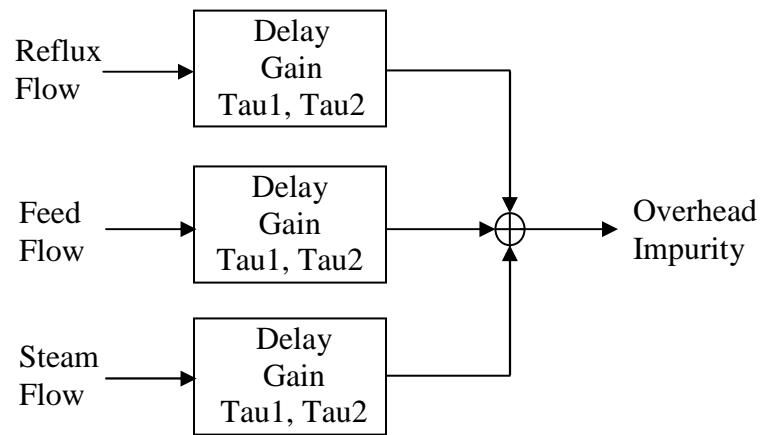
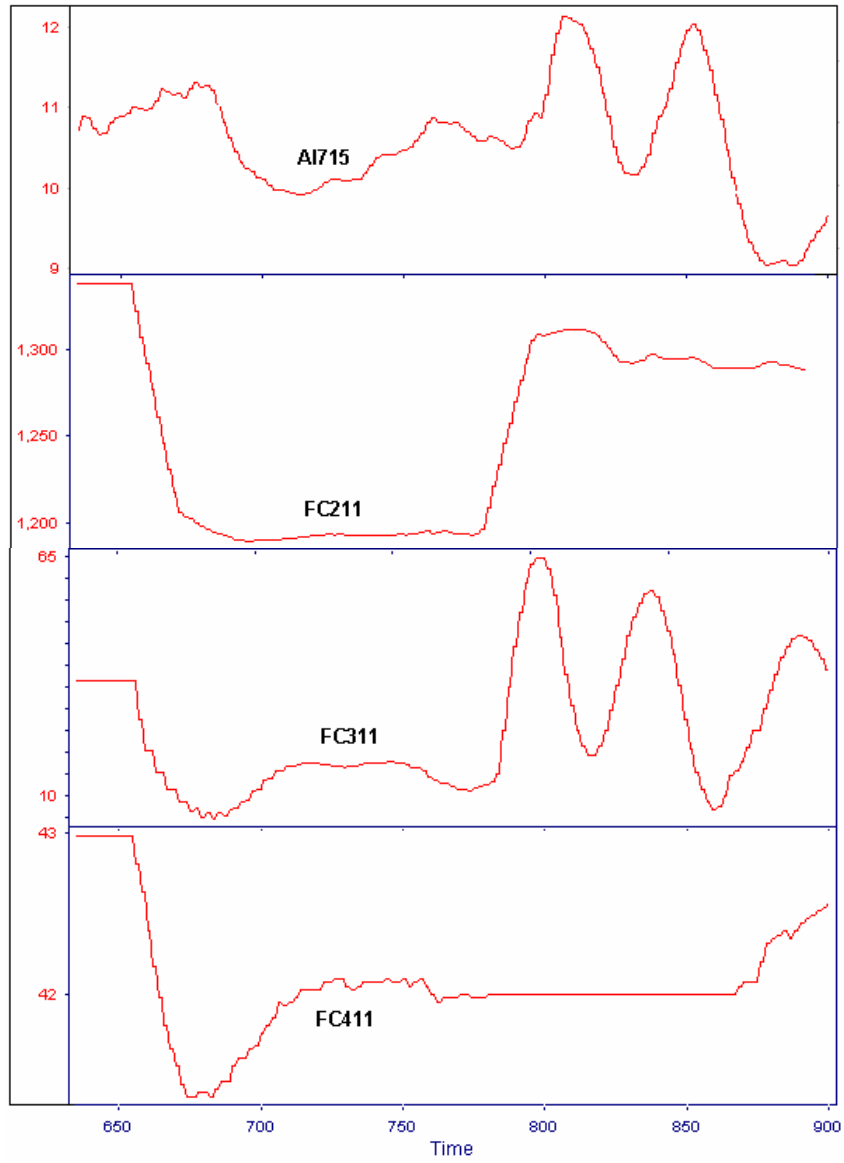




Figure 6. Overhead Impurity versus Reflux, Feed and Steam



Step #2: Specify Filenames

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

Click on File / Plant Data File or the icon  and click on the small box with three dots under Select Plant Data File. Select EX3 PLANT DATA.xls. Then click on Read Data File; click Close.

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.

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 bottom left corner of the screen, click on Start Time and set it to 635. Near bottom right corner, 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:

	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

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.


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.

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 near the bottom 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 Optimize 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 Optimize 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: 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 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 8 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.

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 are 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.

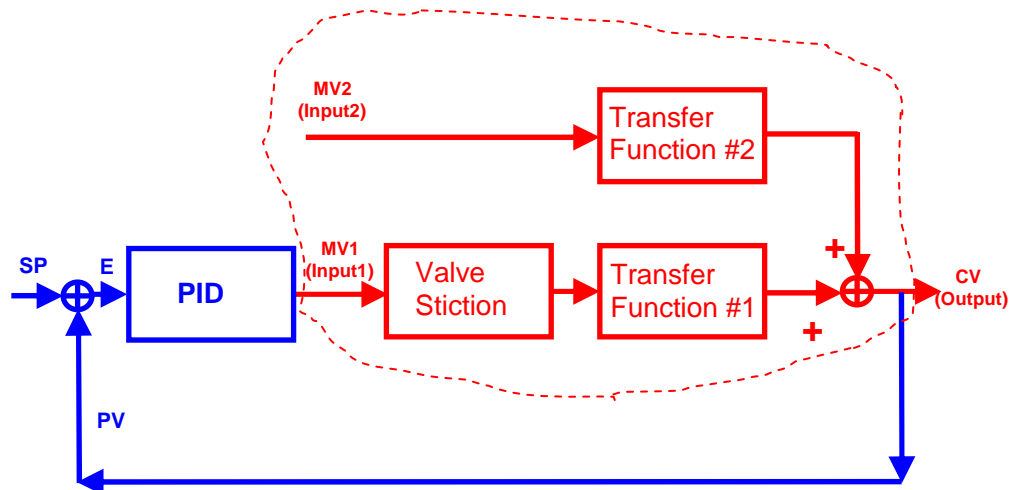
Step #3: Understand Control Schematic

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.

Figure 7. Valve Stiction Identification






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 bottom 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.

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 small box with three dots inside the box to select the Plant Data File. Change the option Files of Type (bottom option inside the popup box) to Step Response Files (*.mdl). Click on Ex5.mdl (this file is supplied with Pitops) and click Open. Click on Read Data File and click on Close.


Pitops asks you to specify initial values for the transfer function parameters, start time, end time and identification method. Click OK. Set Delay = 1, Gain = -1, Tau1 = 25 and Tau2 = 5 (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 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 .

Based on data trend observation, you can fix the delay time at some specific value and then uncheck the Optimize box next to the delay time. Now if you click on Identify , then Pitops will identify the other transfer function parameters whose Optimize boxes are checked. Similarly, if you feel you want to fix the transfer function Gain, then you can also uncheck the Optimize 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 . Click on the small box with three dots inside the box. Make sure that the option Files of Type (bottom option inside the popup box) is Step Response Files (*.mdl). Click on

Ex6.mdl (this file is supplied with Pitops) and click Open. Click on Read Data File and click on Close.

Pitops asks you to specify initial values for the transfer function parameters, start time, end time and identification method. Click OK. 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.

Notice that this model has a small inverse response. To improve the fit, under Transfer Function #1, set Delay to 5 and ***uncheck*** the Optimize box on the far right next to Delay. This fixes the Transfer Function #1 Delay Time to 5. Leave other Optimize boxes for transfer function #1 checked. Based on the red trend in the top plot, we can visually see that only after time = 5, the red trend starts to really decrease. Click on Identify . Notice now Pitops-TFI generates a better fit with a second order transfer function model with delay set fixed at 5.

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 . Click on the small box with three dots inside the box. Make sure that the option Files of Type (bottom option inside the popup box) is Step Response Files (*.mdl). Click on Ex7.mdl (this file is supplied with Pitops) and

click Open. Click on Read Data File and click on Close.


Pitops asks you to specify initial values for the transfer function parameters, start time, end time and identification method. Click OK. 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.

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.

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.

To improve the fit, under Transfer Function #1, set Delay to 3 and **uncheck** the Optimize 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 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 disturbances. 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.

Click on Plant Data File . Click on the small box with three dots inside the box. Make sure that the option Files of Type (bottom option inside the popup box) is Plant Data Files (*.xlr, *.xls). Click on Ex8 Plant Data.xls (this file is supplied with Pitops) and click Open. Click on Read Data File and click on Close.


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. So let us give some initial (guessed) values: Set Delay = 2, and set Gain = 0.1. Click on Run / Simulate  to see the results. Now click on Identify  to improve the fit. The results from Identification are completely wrong and meaningless. Delay is fit to 540 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 Gravity CV (red trend) and Gravity Model (blue trend) (third box from top) are very nicely superimposed from time = 0 until about time = 325. And after that, the Gravity CV and Model trends show a persistent difference (offset).

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 and helped us to identify the correct zero order transfer function.

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

When using the Gravity Identification Method, the identifier will


try to get a good fit between the Gravity CV and Gravity Model displayed in the third trend box from the top on the 3G Plots display.


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 . Click on the small box with three dots inside the box. Make sure that the option Files of Type (bottom option inside the popup box) is Plant Data Files (*.xlr, *.xls). Click on Ex9 Plant Data.xls (this file is supplied with Pitops) and click Open. Click on Read Data File and click on Close.

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. Set initial values of transfer function (starting guessed values) to be: Delay = 1, Gain = 1, Tau1 = 25 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 = 25 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.


Click on Restore button and then select the 3G option under Plots, located also near top right corner of the screen. Now click on Identify . When using the Gradient Method, the Pitops-TFI identifier works to fit the Gradient CV and the Gradient Model shown in the second box from the top.

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

When using the Gradient Identification Method, the identifier tries to get a good fit between the Gradient CV and Gradient Model displayed in the second trend box from the top on the 3G Plots display.

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 noise, 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  and then select EX9.TF.


9.0 A COMPLEX CLOSED-LOOP EXAMPLE

CV-MV data from a plant contain various levels of disturbances and complexities. Many plant DCSs and their data historians (data trending systems) store years of data. Instead of conducting new step tests on the SP or OP, you can literally go back months or years using historical data and identify process dynamics using Pitops-TFI.

Here 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 . Click on the small box with three dots inside the box. Make sure that the option Files of Type (bottom option inside the popup box) is Plant Data Files (*.xlr,


*.xls). Click on Ex10 Plant Data.xls (this file is supplied with Pitops) and click Open. Click on Read Data File and click on Close. 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

Set Plots to the 3G option. Set initial values of transfer function (starting guessed values) to be: Delay = 1, Gain = 1, Tau1 = 25 and Tau2 = 0. Click on Run / Simulate .

Select Geometric method and examine the trends. Notice that with the Geometric identification method, the Gradient CV looks noisy and Gravity CV looks even noisier.

The Gradient and Gravity identification methods help to dampen/reduce the effects of unmeasured disturbances, but they tend to amplify the effect of fast random noise. This noise amplification can pose problems to the transfer function identification. However, the effect of noise can be dampened or reduced by using some data filtering.

Note that 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.

Step #3: Select the "Gravity" Identification Method


Now set the Identification Method to Gravity. Toggle from Gravity to Geometric back and forth several times and compare how the Gravity CV becomes smooth using the Gravity method and noisy for the Geometric method.

Step #4: Select the Filter Option

Pitops-TFI provides filtering option on the CV data to reduce the harmful effects of noise and improve the chances of getting good transfer function parameters. When using the Gravity method, Pitops-TFI defaults the filtering level automatically to High.

In this example, the CV signal is not very noisy and High filtering makes the data appear too highly filtered. Click on the Filter button displaying High and select Low.

Step #5: Study Identification Results


With identification method = Gravity and Filter = Low, click on click on Identify . Pitops now calculates the transfer function parameters. Notice that the Gravity CV (red trend) and Gravity Model (blue trend) shown in the third plot window from the top match reasonably well (identification is successful). If not, we could have, at this stage tried different filtering options and then click on Identify again.

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.

When using the Gravity Identification Method, the identifier tries to obtain a good fit between the Gravity CV and Gravity Model displayed in the third trend box from the top on the 3G Plots display.

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 impossible (the identified transfer function parameters would have been meaningless). 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 AND RECOMMENDATIONS

Some guidelines and recommendations on how to identify transfer functions are given below.

These 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. 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.

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 are based on open-loop data and example #3 is based on closed-loop data. Notice the box type pulses for input variables in examples #1 and 2 (characteristic of open-loop tests). Input signals in example #3 are not "clean" pulses, but were moved by an advanced control system, which was adjusting their setpoints every minute.

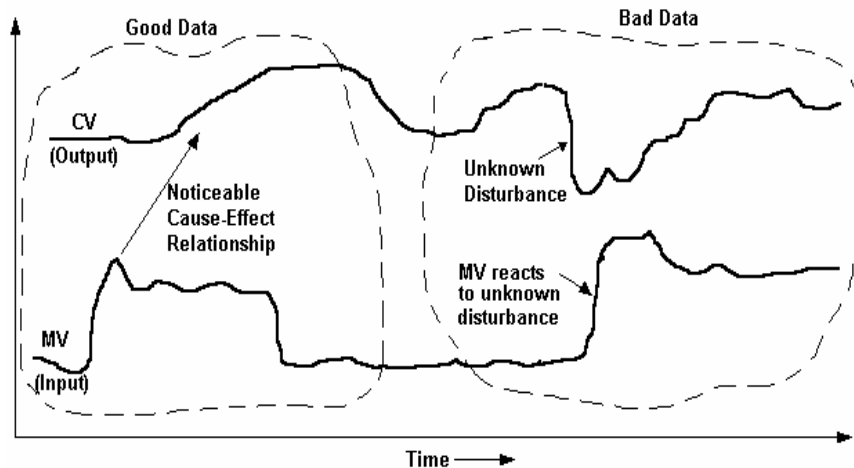
Pitops-TFI can identify transfer function parameters successfully using any of the three cases:

- 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.

Figure 8. Good and Bad Data




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.

3. **Initial Guesses for Transfer Function Parameters**

Before clicking on Run / Identify , approximate transfer function parameters must be specified. Consultation with plant operators or engineers familiar with the process is recommended. Based on process and dynamics knowledge, it is fairly easy to estimate approximate values of transfer function parameters.

For example, if the real dead time in a process is 10 minutes, an initial estimate of 1-15 minutes is a good initial guess. Similarly, if the real process gain is 5.0, then initial guesses of 0.1-10 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, Pitops may not always be able to determine improved parameters.

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 20000 time units.

5. **Optimize Check Box**



In addition to specifying the initial transfer function parameters, the Optimize check box must be either checked or unchecked for each transfer function parameter. The Optimize 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 Optimize 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.

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.

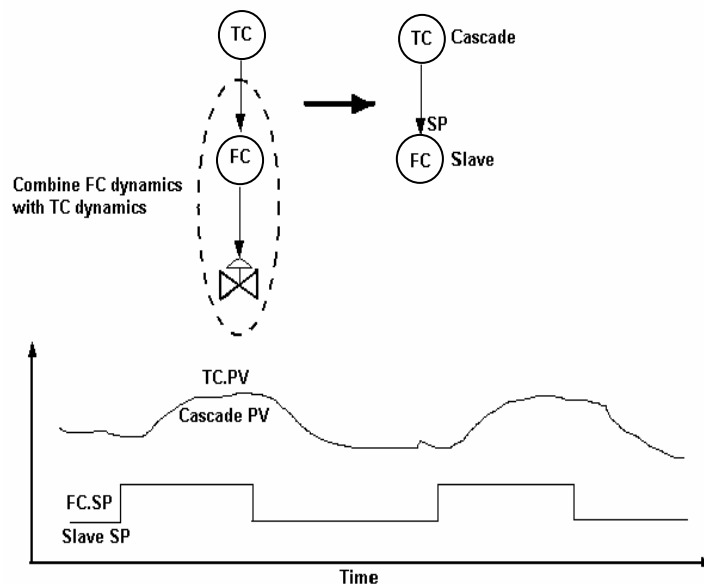
At least one of the transfer function Gain values must be non-zero before clicking on the Run / Identify  function. If all gains are zero, then Pitops will request you to set some reasonable values for the transfer function parameters before clicking on Run / Identify .

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.

Figure 9. Cascade PID with Fast Slave Dynamics



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.

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.

PART C: PITOPS-TFI SCREENS AND MENU OPTIONS

CONTENTS

- 1.0 TRANSFER FUNCTION IDENTIFICATION
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PART C: PITOPS-TFI SCREENS AND MENU OPTIONS

Part C explains all Pitops pop-up, pull-down menus and screen options. Part C is intended to be used as the software reference manual.

The user should configure the sample examples provided in Part B and familiarize with Pitops-TFI before applying Pitops to brand-new transfer function identification problems.

Part C can be used to clarify specific queries on any of the menus and screen options that may arise while configuring new problems.

The user ought to follow all steps in Part B first and then refer to detailed explanations in this section on specific variables, menus and plots on an as-needed basis.

1.0 TRANSFER FUNCTION IDENTIFICATION

The Transfer Function Identification (TFI) module is used to identify transfer function parameters based on historical plant data. To use this option, historical plant data in the form of Excel files are required. Pitops reads the historical data and then identifies the transfer function parameters (process gain, dead time and time constants). An approximate starting guess for each of the transfer function parameters must be supplied before the identification process can be started.

Pitops-TFI provides three methods for transfer function identification. They are called the 3G Identification Methods: Geometric, Gradient and Gravity. These are explained below:

1.1 GEOMETRIC METHOD

When you start a new case file, Pitops-TFI defaults to the Geometric Method for transfer function identification. Try to use this method first.

The Geometric method uses raw CV, MV data for transfer function identification. Using the raw data gives the maximum "**richness**" in terms of data quality for transfer function

identification. "**Richness**" refers to the extent of available cause-and-effect dynamics information available in the data. When there are not many unmeasured disturbances, drifts and nonlinearities in the raw data, then the data are "**rich**" and the Geometric method works very well.

However, real plant data often contain undesirable components such as superimposed noise, drift, disturbances and nonlinearities. One of the limitations of the Geometric Method is that it is sensitive to these disturbing components. An example of an unmeasured disturbance is a sudden rain storm that may appear to mysteriously cool a temperature, whose transfer function you are trying to identify. If the impact of these disturbances on the CV is significant, then the Geometric Method for transfer function parameter identification may give poor results.

Any time you feel the transfer function parameters identified by Pitops-TFI using the Geometric Method look obviously wrong and/or do not match with your process knowledge and understanding, then try the other two identification methods-Gradient Method and Gravity Method.

1.2 GRADIENT METHOD

If you are identifying first order or second order transfer functions, and if the Geometric Method did not produce good transfer function parameters, then try the Gradient Method.

The Gradient Method algorithm has the capability to reject unmeasured disturbances and drift better than the Geometric Method and may identify transfer function parameters more accurately.

It is a good idea to try both Geometric and Gradient Methods and compare the transfer function identification results from both methods.

Note that the Gradient Method may not work well with zero order (ramp/integrating) transfer functions, but will work well for first and second order transfer functions.

1.3 GRAVITY METHOD

The Gravity method can be used for all transfer function types: zero, first and second order.

The Gravity Method algorithm has stronger capability to reject unmeasured disturbances than both Gradient and Geometric methods.

For zero order transfer functions, try both Geometric and Gravity Methods and compare the transfer function identification results from both methods.

Furthermore, the Gravity Method is likely to work the best on first and second order transfer functions when external disturbances are strong and when the Geometric and Gradient methods failed to produce good transfer function parameters.

1.4 FILTER OPTION


If CV data are noisy, then filtering can help to identify the transfer function parameters more easily and more accurately.


Pitops-TFI allows various levels of data filtering. Pitops-TFI automatically sets zero filtering for Geometric method, low filtering for Gradient method and high filtering for Gravity method, but you can change these default filter settings depending on the noise and disturbance levels.

Depending on noise level, changing the Filter option could help get better results. Click on the Filter button see all the filtering options: None, Weak, Low, Medium, High, Very High and Maximum. Use higher filtering on noisier data and lesser filtering on smoother data.

2.0 TRANSFER FUNCTION PARAMETERS

You will see the transfer function parameters on the right side of the screen: Delay, Gain (Process Gain), Tau1 and Tau2 (first order and second order time constants). You must enter some reasonable initial values for these transfer function parameters.

After entering the transfer function parameters, you can click on Run / Simulate  to see the model prediction (blue colored trend) in the top plot window. The blue trend shows the transfer function model prediction based on your entered transfer function parameters and the data from the Input Files.

Each transfer function parameter is provided with an Optimize option check box. If the box is checked, then the variable will be changed (improved) when the Run / Identify  option is clicked. If the box is unchecked, then the variable will be set fixed at the value specified.

Note that the Optimize check boxes are relevant only to the Identify function and have no effect on the Simulate function. The Simulate function shows the transfer function model predictions based on the transfer function parameters seen on the right side of the screen, whereas the Identify function determines improved parameters.


The Optimize check box is provided to allow fixing known transfer function parameters. In some cases, based on process knowledge and experience, certain parameters may be accurately known. E.g.: if the delay is known to be 10 minutes, then we can set the delay fixed to 10 minutes (uncheck the box for Delay). Then Pitops will identify the process gain and first/second order time constants only, while keeping the delay fixed at 10 minutes. Similarly, the gain or time constants may be fixed if they are accurately known.

If all parameters are set to fixed values (all boxes unchecked), then the Identify function will result in no changes to the initial transfer function parameters provided by the user.

If zero is entered for any parameter, that parameter will be set fixed at zero by the Identify function.

2.1 TRANSFER FUNCTION #1

Use this option to specify transfer function parameters for the first transfer function.

The Simulate  function simulates the transfer function response based on the specified transfer function parameters (Delay, Gain, Tau1 and Tau2).

The Identify function reads the initial specified transfer function parameters and then changes (improves) them based on the trend data read from the data files.

2.2 DELAY

Enter the best guess for delay in the selected time units. If you want Pitops to determine the dead time, the Optimize box must be checked. If you are sure that the entered value is the correct dead time, then the box must be unchecked. With an unchecked box, the Delay will be set fixed at the specified value.

Typical starting values are 1 – 15. Try 2 – 5 as a first pass.

2.3 PROCESS GAIN

Enter the process gain in engineering units. For example, consider the case of temperature control by manipulating steam flow. Let's say that changing the steam flow by 5.0 ton/hour results in 4°C change in temperature. Then the process gain can be calculated as $= (4.0 / 5.0) = 0.8 \text{ } ^\circ\text{C} / (\text{ton/hour})$. Note the units for the process gain in this example: delta temperature ($^\circ\text{C}$) / delta steam flow (ton/hour). Generically stating, the process gain is the change in the output variable per unit change in the input variable.

Note that Pitops will identify the process gain during the optimization run when the Identify function is clicked. The initial gain entered by the user needs to be only an approximate guess.

For example, if the process gain is 0.8, then values such as 0.01 to 5 (say) are reasonable starting values. It is important to specify the correct sign for the gain (positive or negative). If increasing the input variable (MV) causes the output variable (CV) to decrease, then the process gain is negative and a negative gain must be entered. If the initial guess is rather

poor, then the Identify function may not be able to find the best fit for the transfer function parameters.

Typical starting values are 0.01 to 100 for positive gains and -100 to -0.01 for negative gains, but they really depend on the process and can vary a lot. Consult plant operations or study historical data to determine a reasonably good guess.

2.4 TAU1 (TIME CONSTANT #1)

Enter the best guess for the first order time constant in the selected time units.

If you want Pitops to determine the first order time constant, check the Optimize box. If zero is specified for Tau1, this is interpreted as a zero order transfer function. Pitops will then try to fit a zero order transfer function (with both Tau1 and Tau2 set to zero).

Typical starting values are 5 – 100. Try 25 as a first pass.

2.5 TAU2 (TIME CONSTANT #2)

Use this option only for second order transfer functions. If you wish to fit a first order transfer function, set this parameter to zero.

If you wish to fit a second order transfer function, enter the best guess for the second order time constant in the selected time units in this field.

If you want Pitops to determine the second order time constant, the Optimize box must be checked.

Typical starting values are 5 – 100. Try 25 as a first pass.

2.6 TRANSFER FUNCTION EQUATION

On the right side of the screen, the Process Transfer Function equation formats are displayed, as shown below:

$$G(s) = \frac{\text{Gain } e^{-\theta s}}{\tau_2 s^2 + \tau_1 s + 1}$$

$$G(s) = \frac{\text{Ramp } e^{-\theta s}}{s}$$

Note that the top equation is for first and second order transfer functions. On Pitops-TFI main screen, the time constants Tau1 and Tau2 are the same as the denominator τ_1 and τ_2 shown in the above equation. Note that Pitops-TFI uses the polynomial form and not the factorial form for the denominator of the above transfer function equation.

If you are trying to fit a zero order (ramp/integrating) type transfer function, then both Tau1 and Tau2 must be set to zero. The Gain then becomes the Ramp Rate and there are no time constants. The bottom equation (shown above) represents the zero order equation, where "Ramp" in the equation is the Ramp Rate.

If you are trying to fit a first order transfer function, then τ_2 must be set to zero. Then, the denominator of the equation has the form $(\tau_1 s + 1)$.

If you are trying to fit a second order transfer function, then both τ_1 and τ_2 must be set to non-zero. Then, the denominator of the equation has the polynomial form $(\tau_2 s^2 + \tau_1 s + 1)$. Note that this is a polynomial form, not a factorial form.

2.7 TRANSFER FUNCTION #2

In most industrial processes, a controlled variable is affected by more than one input. In the case of a distillation column, the product purity is typically affected by reflux flow, reboil flow and column feed flow.

Ideally, if only one of the three input variables can be changed while the other two are fixed, the dynamics identification would be relatively simple, since this would be a single input/ single output (SISO) situation.

But in practice, it may not be possible to allow only one of the inputs to change while the rest are fixed. Typically, several variables may be changing at various times. Pitops allows up to three input signals to be analyzed simultaneously.

If your identification problem needs a second MV (input), then under Transfer Function #2, enter the transfer function parameters for the second transfer function. Data for the second MV is required in the Excel plant data file (column #4).

If your identification problem is a single input problem, set all four parameters (Delay, Gain, Tau1 and Tau2) under Transfer Function #2 to zero.

2.8 TRANSFER FUNCTION #3

If your identification problem needs a third MV (input), then under Transfer Function #3, enter the transfer function parameters for the third transfer function. Data for the third MV is required in the Excel plant data file (column #5).


If your identification problem is a one or two input problem, set all four parameters (Delay, Gain, Tau1 and Tau2) under Transfer Function #3 to zero.

3.0 FILE


The File pull-down menu button is located near the top left corner of the screen. It is used to read and save Pitops-TFI simulation case files. After a simulation is configured in Pitops-TFI, the whole data set can be saved conveniently to a file for later use. The File pull-down menu button provides the following file operations for opening and saving files. It also is used to generate vector files (explained below) and also to print plots and reports:

3.1 NEW CASE FILE


New Case File erases all current data and initializes with default values (mostly zeros). This is a convenient way to start a new run. Data from the previous run is erased and the

simulator is ready for a new case. The icon  is also denotes New Case File.

3.2 OPEN CASE FILE


Open Case File function allows reading a previously saved case file (case files are described in a later section below). The icon  also denotes Open Case Files. The case file contains all configured data: transfer function parameters, stiction value and plant data filename. This is a convenient means of restarting the case at a later time.


When you exit Pitops, all information is automatically saved to a special start-up case file. This file is automatically read after Pitops is restarted at a later time. Thus, you can conveniently exit and re-start from where you left.

To open an existing case file, click on Open Case File  and then select the appropriate file from the window and click on Open.

It is recommended that case files in the TFI module should be given filename extension ".**TF**". This is not a requirement, but a good naming convention to follow. The Open Case File function expects the case filename extensions to be ".**TF**". If different extensions are used, then *File Type* should be changed to *All Types (*.*)* to view the case files.


3.3 SAVE, SAVE AS

The File / Save function saves all current information to the existing file name on the hard disk for future use. All transfer function parameters and plant data filename are saved to the current simulation case file. The icon  is also denotes Save.

This case file can be restored at a later time by using the Open Case File  option described above.

To save the current configuration data to a file with a different name, click on File / Save As and then specify the new case file name as desired.

3.4 PLANT DATA FILE

Click on File / Plant Data File or the icon  to specify the plant data filename. Click on the small box with three dots inside to select the filename. Pitops-TFI can read files in either Excel format or in Text format. See the option Files of Type at the bottom inside the Select Plant Data File box. Using the down arrow, you can choose from two options: **Plant Data Files (*.xlr, *.xls)** or **Step Response Files (*.mdl)**.

The default option is the Plant Data Files option and is explained below:

1. Plant Data Files (*.xlr, *.xls)

Pitops identifies transfer function parameters based on historical plant data in Excel format.

This section explains the naming convention of the files and the file format expected by Pitops-TFI.

As an example, open the file EX3 PLANT DATA.xls provided with the Pitops-TFI software.

The first column contains time stamps (this column is ignored by Pitops-TFI, but this column is required). The Sample Time is defined as the time period between consecutive data samples (rows in the file). Pitops-TFI does not read the first column (time column) and does not estimate the sample time from the plant data file. But sample time can be specified in Pitops-TFI. Sample Time specification is explained further below in this document.

The actual plant data begin in the second column and fourth row (this is defined in the file **default.ini** and is explained below).

The first row contains tagnames for the CV and MVs. The second and third rows may be left blank or used to specify some tag descriptors and engineering units. Data begins from fourth row onwards.

The second column must contain data for the CV (Controlled Variable) data.

The third column must contain MV#1 (Manipulated Variable #1).

The fourth column contains MV#2 (Manipulated Variable #2). If there is no MV2, then this column can be blank (see data file named EX1 PLANT DATA.xls).

The fifth column contains MV#3 (Manipulated Variable #3). If there is no MV3, then this column can be blank (see data file named EX1 PLANT DATA.xls).

The file structure (column and row number where the actual plant data start) can be changed. For all supplied files and examples, plant data started in Row# = 4 and Column# = 2. If your plant data generating system generates files with a different column or row number, then the Pitops file reading format can be changed also.


To change the plant data file structure to suit your plant, open the file called ***Default.ini*** supplied with the Pitops-TFI software. Then, using Notepad editor modify the Row# and Col# as needed and save the file. Exit and re-start Pitops-TFI for the changes to take effect.

For complete details and examples on how to use plant data files in Excel format, see Sections 2, 3, 4 and 5 in Part B.

2. Step Response Files (*.mdl)

Pitops can read step response files in text format and then fit transfer function parameters. For complete details and examples on how to use step response files, see Section 6 in Part B.

3.5 PRINT


Click on Files / Print or the icon  to print the transfer function prediction plot.

3.6 EXIT


To exit Pitops-TFI, either click on File and Exit, or click on the Windows "X" icon on the top right corner of the screen. Exit is used to exit the Pitops-TFI module. A "Yes" or "No" confirmation is prompted.

If No is selected, exit is cancelled. If Yes is selected, Pitops-TFI module exits. Before exiting, all configuration data at time of exit are saved to a configuration file. This file is opened and all data are restored when the Pitops-TFI program is started again later. This allows the user to conveniently continue the last run after exiting the program.


4.0 SIMULATE

Click on Run / Simulate  to run the Pitops simulator. The simulator reads the transfer function parameters entered by the user and the plant data file. The model prediction based on the transfer function parameters entered is displayed as a blue colored trend. The data from the plant data file is displayed as a red colored trend.

5.0 IDENTIFY

Click on Run / Identify  to find improved transfer function parameters that match the Output file data better than the initial set of transfer function parameters.

Pitops reads the initial (guessed) transfer function parameters entered by the user and then runs an optimization algorithm to minimize the error between the measured output signal (specified in the trend data file) and the model predicted signal. The model predicted signal (output) is based on the transfer function parameters and the input signal. The optimization algorithm starts with the initial transfer function parameters provided by the user and searches for an improved set.

If you want to go back to the original values of the transfer function parameters before you clicked on Run / Identify 


button, then click on the Restore button. The Restore button is a convenient way to run various "Identify" cases with some changes to the starting (guessed values) of the transfer function parameters.

5.1 SUCCESS MESSAGE

If the identification run improves the transfer function parameters, then, Pitops-TFI displays a "success" message. This means that the integrated error between the measured and the predicted (model) signals was reduced.



5.2 FAIL MESSAGE

If the identification run could not improve transfer function parameters, then, Pitops-TFI displays a "fail" message indicating that no improvement was made. This means that either the transfer function parameters are already very close to the best (optimum), or that the starting guess for the transfer function parameters was poor.

You may modify the transfer function guesses and then restart the identification algorithm by clicking on Run / Identify .

5.3 LOCAL MINIMA

Different combinations of initial transfer function parameters may result in several local minima. It may be desirable to start with different sets of initial transfer function parameters and then examine the optimized parameters for each case. Optimum results from different initial guesses for the transfer function parameters combined with knowledge about the process will help in narrowing down the range of values for the transfer function parameters.

Note that in some cases, changing the initial transfer function parameters and clicking again on the Run / Identify  button can generate further improved transfer function parameters. It is a good practice to try different sets of initial guesses for the transfer function parameters and clicking on Run / Identify  button.

6.0 START TIME AND END TIME

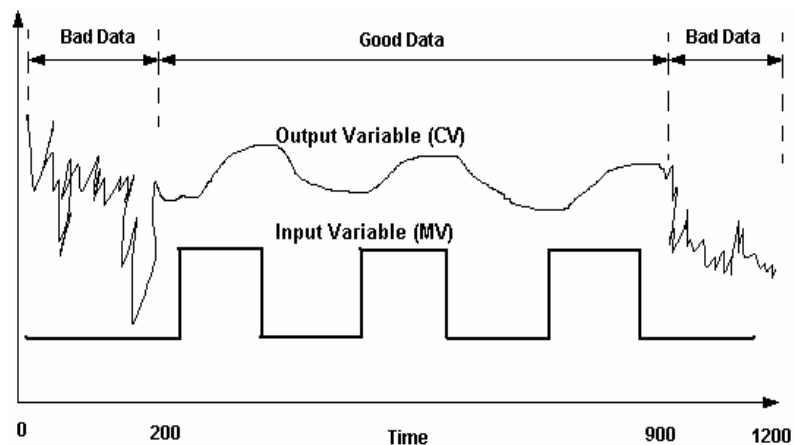
The Start Time and End Time fields are located near the bottom of the screen.

The Start Time specifies the start time to start processing the data. For example, the files described above may contain some window of bad data because of (say) failed instrument signal or some abnormal process upset. E.g., if the file had 1200 data points and if the data from time = 0 to time = 200 are bad, then type 200 as the start time. See Figure 10.

The End Time specifies the last sample point to use. For example, as shown in Figure 10, data between 900 and 1200 are bad because of a failed instrument signal or some abnormal process upset. In this case, type 900 as the end time.

Based on the specified start and end times, data points between 200 and 900 only will be used for transfer function identification. Data between 0-200 and 900-1200 will be ignored. The start and end times thus allow taking out bad or undesirable data from the data window used for transfer function parameter identification.

Figure 10: Define Start Time and End Time



7.0 SAMPLE TIME

The Sample Time is displayed to the right of the End Time. The sample time is the time period between two consecutive data samples in the plant data file. Figure 11 illustrates the Sample Time concept. Figure 11 displays a portion of a typical plant data file containing plant data that can be read by Pitops-TFI. The plant data start in row #4 and goes to the end of the file. The time stamps corresponding to each data row are shown in column #1. Based on the data and time stamp shown in column #1, the Sample Time is 3 seconds. Since there are numerous types of possible data and time stamp formats, for reasons of simplicity, Pitops-TFI does not read the time format in column #1 but asks you to specify the Sample Time directly.

Figure 11: Sample Time in Plant Data File

	A	B	C	D
1	TIME	TC107	FC505	PC209
2		Tray 12 Temp	Feed Flow	0vh Pres
3				
4	05/Dec/07 10:30:00	8.646741867	8.62894058	49.8224182
5	05/Dec/07 10:30:03	8.648562431	8.62894058	49.788105
6	05/Dec/07 10:30:06	8.644310951	8.62894058	49.7948189
7	05/Dec/07 10:30:09	8.640060425	8.62894058	49.8048782
8	05/Dec/07 10:30:12	8.626669884	8.62894058	49.821785

Using the illustration in Figure 11, you must specify the Sample Time to be 3 on the Pitops-TFI screen (value is located to the right of the End Time field).

The Start Time and End Time are multiplied by the Sample Time so that the Time Axis (X axis) is scaled to show the correct time unit.


For first and second order transfer functions, the Delay Time, Tau1 and Tau2 are multiplied by the Sample Time so that their

values are displayed in the correct time units. For first and second order transfer functions, the process gain is not time-dependent and hence is not dependent on the Sample Time.

For zero order transfer functions (when both Tau1 and Tau2 are zero), the Delay Time is multiplied by the Sample Time so that its value is displayed in the correct time units. For zero order transfer functions, the process gain is also called the ramp rate which is time-dependent and hence it is a function of the Sample Time. The ramp rate is divided by the Sample Time so that the ramp rate unit (change in CV/change in MV/time) is scaled correctly.

For any questions or clarifications on the Sample Time, please send your query to info@picontrolsolutions.com.

8.0 ERROR

The Error value is displayed near the bottom right corner of the screen. You cannot modify this field; this is calculated by Pitops-TFI. The error is the difference between the model prediction and the output file data calculated at every time unit for the complete time window specified by the Start Time and End Time. In other words, the Error is the difference between the red and blue trends on the model prediction plot. When you click on the Run / Identify  button, Pitops tries to minimize the Error value.

9.0 VALVE STICTION

Control valves can stick, have “loose-play” or “deadband” in their hardware linkages. As the PID OP changes, the valve may not move at all until the PID OP has changed by certain minimum threshold limit. This limit is called **Stiction**. The stiction problem can be because of valve sticking or loose linkages. Stiction is often seen in compressor turbine nozzles, old control valves not maintained in a long time, valves servicing corrosive, abrasive materials or with poor valve hardware. Figure 12 illustrates a control valve problem.

Only when the valve is bumped up three times, a noticeable change in flow is finally seen. This is clear proof of valve

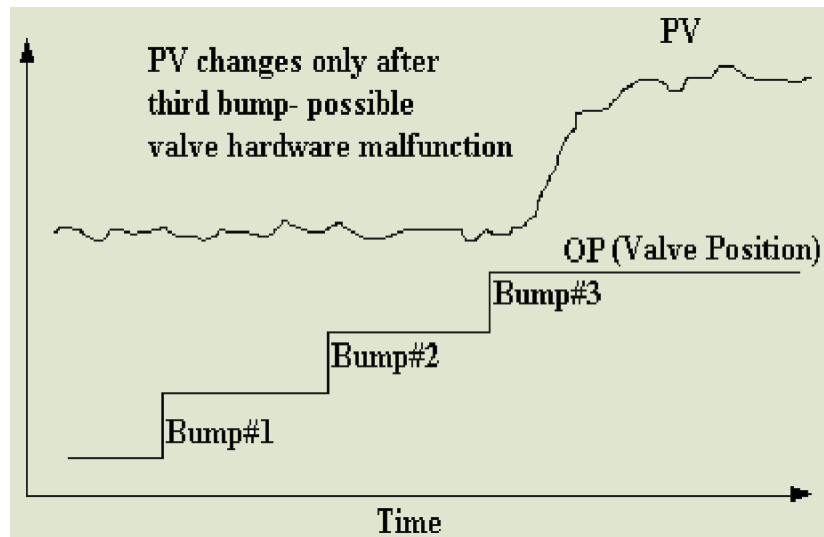
stiction. If there was no stiction, then the flow (PV) should have increased for the first two valve bumps also.

A typical relationship between the PID output and the actual valve position is shown in Figure 13.

Notice that once the PID OP has moved enough to overcome the stiction deadband, then the valve moves in accordance to the PID OP.

If the direction of the PID OP changes, then the valve will not move until the stiction deadband is traversed again.

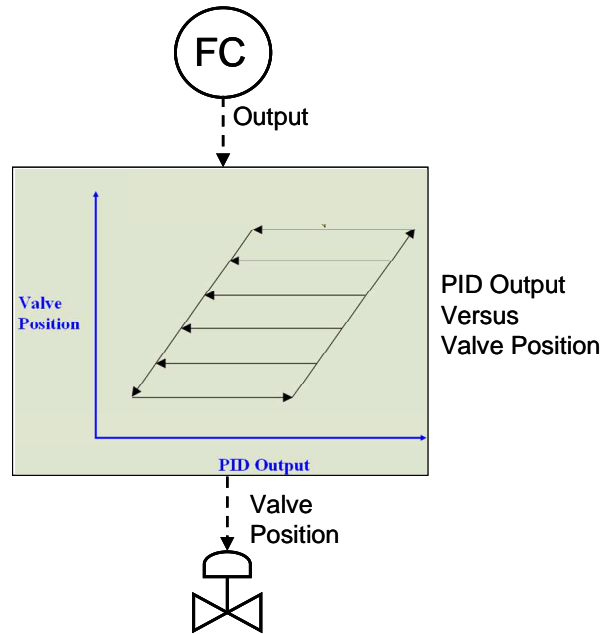
Figure 12. Pulse Disturbance Signal




Pitops-TFI software simulates valve stiction. See the field labeled Valve Stiction located near the bottom right corner of the screen. Typical values of valve stiction are 0.5% to 25%. Valve stiction of over 10% is on the high side.

Pitops-TFI identifies valve stiction and the transfer function of the control loop using plant data. Data can be closed-loop, open-loop or a mixture of both. Refer to a complete step-by-step example on PID simulation and optimization in the presence of valve stiction described in Part B, Section 5.

Figure 13. Stiction Plot showing PID Output versus Valve Position



10.0 HELP

Click on [Help / Help Topics](#) in the top tool bar or click on the icon  to open the Pitops-TFI User Manual.

Click on [Help / About](#) in the top tool bar to see information on the Pitops-TFI software product.

For any questions or clarifications on the Pitops-TFI, please send your query to info@picontrolsolutions.com.