Chapter 6
Controller Design Using *Design Tools*

Defining Good Process Test Data

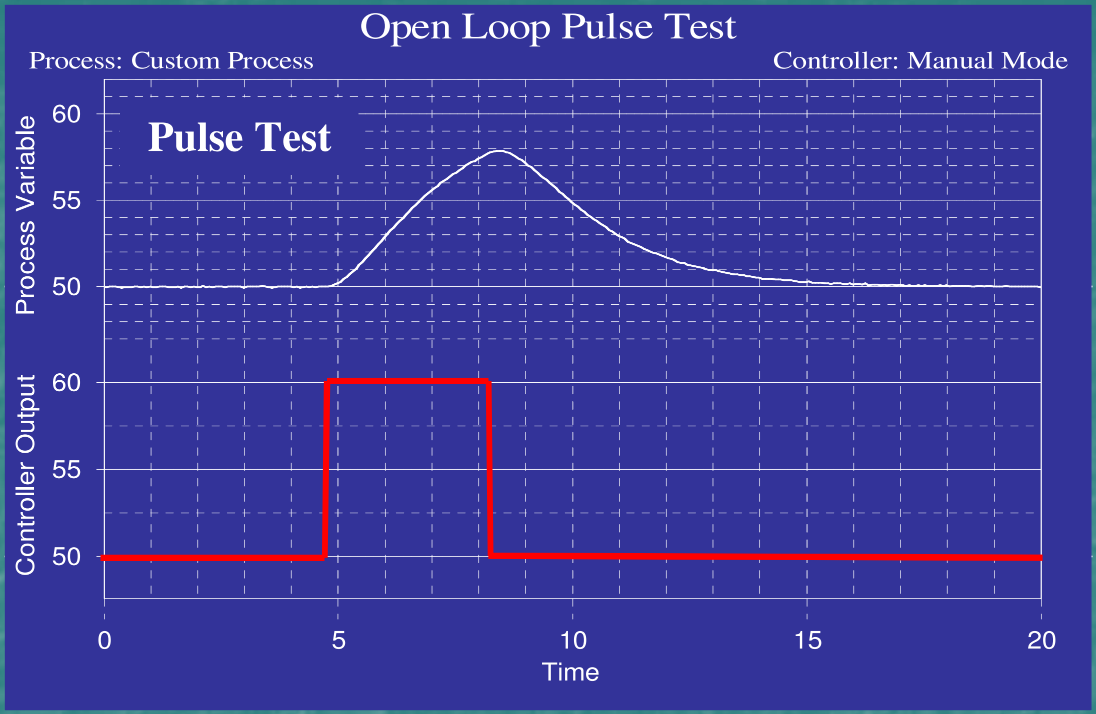
- The process should be at steady state before data collection starts
- The test dynamics should clearly dominate the process noise
- The disturbances should be quiet during the dynamic test
- The model fit should visually approximate the data

- (The first data point should equal the initial steady state value)

Dynamic Testing

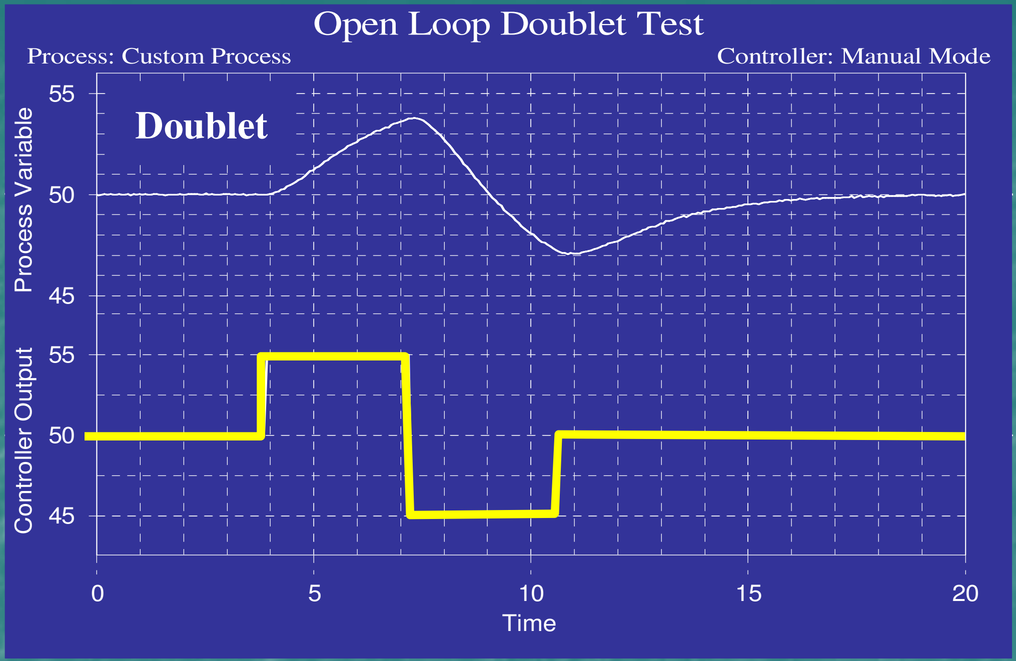
- **Limitations of the Step Test**
  - It moves the process away from the desired operating level for too long causing significant off-spec production
  - Generates data on only one side of initial steady state
- **Limitations of All Open Loop Tests**
  - Open loop tests require operating personnel to put a loop in manual "just" to generate dynamic process data
  - Popular open loop tests include: step, pulse, doublet, PRBS

Pulse Test



- Pulse test is two step tests performed in rapid succession
- *Desirable*: starts from and returns to an initial steady state
- *Undesirable*: data generated on one side of this steady state (which presumably is design level of operation)

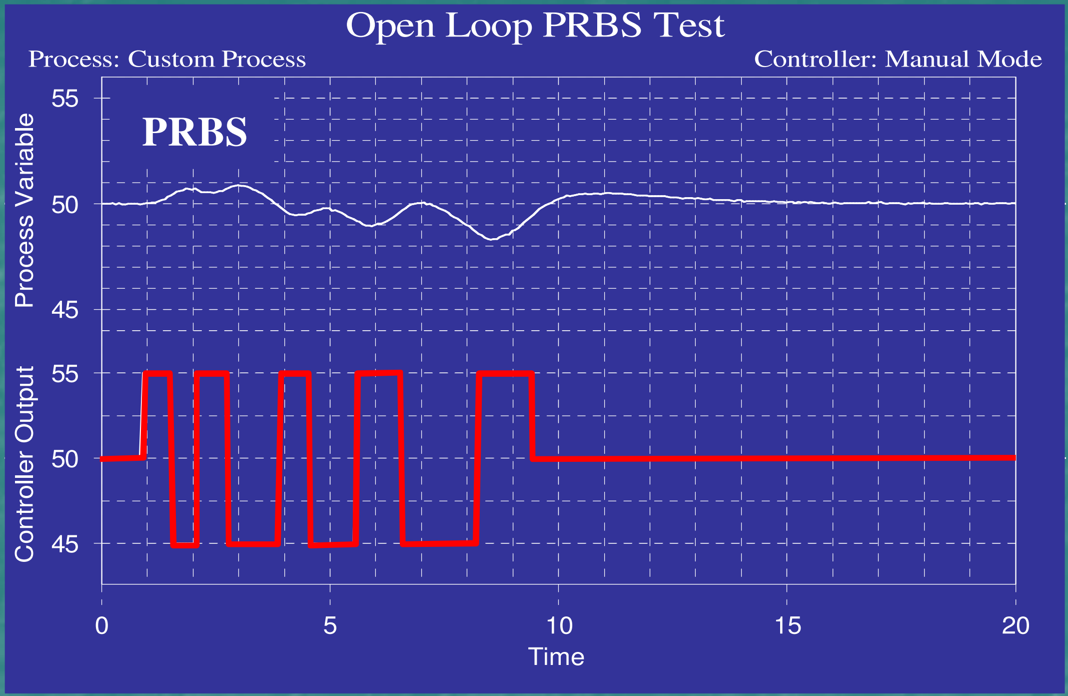
Doublet Testing



- A doublet, two pulses in opposite directions, is desirable:
  - returns quickly to the design level of operation
  - produces data both above and below the design level
  - relatively small deviation from the initial steady state

Doublet is preferred by many practitioners

PRBS Testing



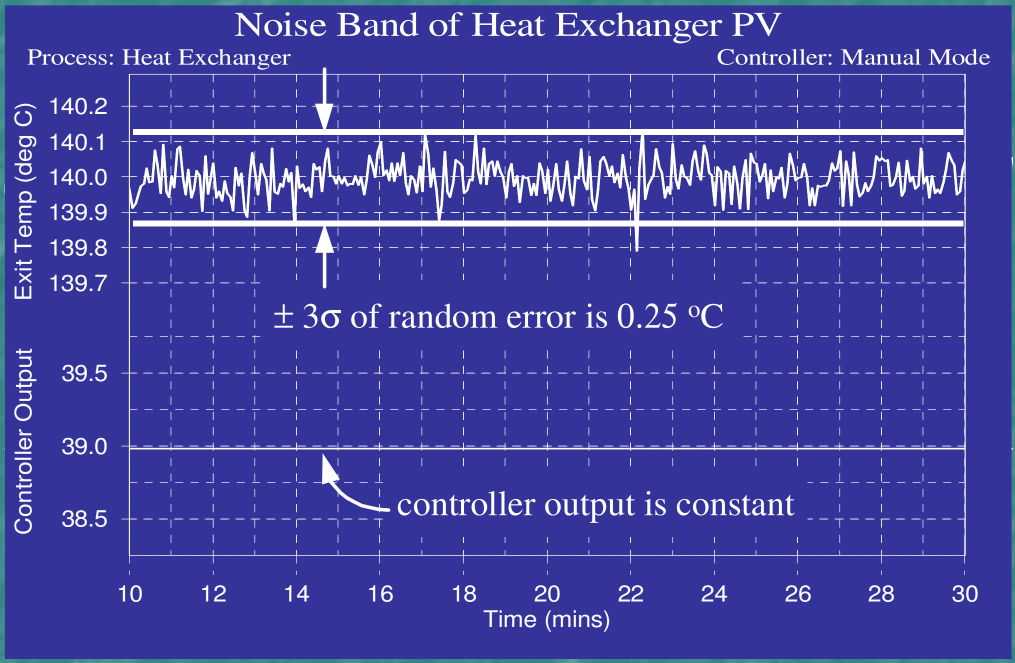
- Pseudo-random binary sequence (PRBS) tests are a sequence of controller output pulses that are
  - uniform in amplitude
  - alternating in direction
  - random in duration

PRBS Testing

- Desirable:
  - start and return to the design level of operation
  - produces data both above and below the design level
  - produces the smallest maximum deviation from the initial steady state of all open loop tests
- A proper PRBS design requires specifying:
  - controller output initial value
  - controller output pulse amplitude
  - average duration of each pulse
  - standard deviation of the random change in pulse duration around this average
  - length of the experiment itself
- If you perform the experiment a number of times in a search of a "best" test, stick with the quick and practical doublet test

Noise Band and Signal to Noise Ratio

- To obtain good data for tuning, the controller output must force the process variable to move at least 10 times the *noise band* (signal to noise ratio ≥ 10)



- Here, controller output should be moved far and fast enough to cause the measured exit temperature to move at least 2.5 °C
- Noise band includes measurement noise *and* process noise

Automated Controller Design Using *Design Tools*

Time	**Controller Output**	**Process Variable**
0.00	70.0	4.00
0.15	70.0	4.01
0.30	80.0	3.99
0.45	80.0	4.03
0.60	80.0	4.09
0.75	80.0	4.17

process must be at steady state
when data collection begins

first PV value must equal
the true initial steady state

- *Design Tools* fits dynamic models to process data in text files with (at least) three columns:
  - a time stamp
  - manipulated variable data (usually controller output)
  - measured process variable data

Automated Controller Design Using *Design Tools*

- **Step 1:**
  - Find model parameters that minimize sum of squared errors:

$$SSE = \sum_{i=1}^{N} [\text{Measured Data}_i - \text{Model Data}_i]^2$$

  - The smaller the SSE, the better the model describes the data
  - To obtain a meaningful model:
    - process must be at steady state before data collection begins
    - the first point in the file must equal this steady state value
  - If these are not true, the model will be of little use

- **Step 2:**
  - Uses the FOPDT model parameters in correlations to compute initial controller tuning values

Example Fit of Heat Exchanger Doublet Test

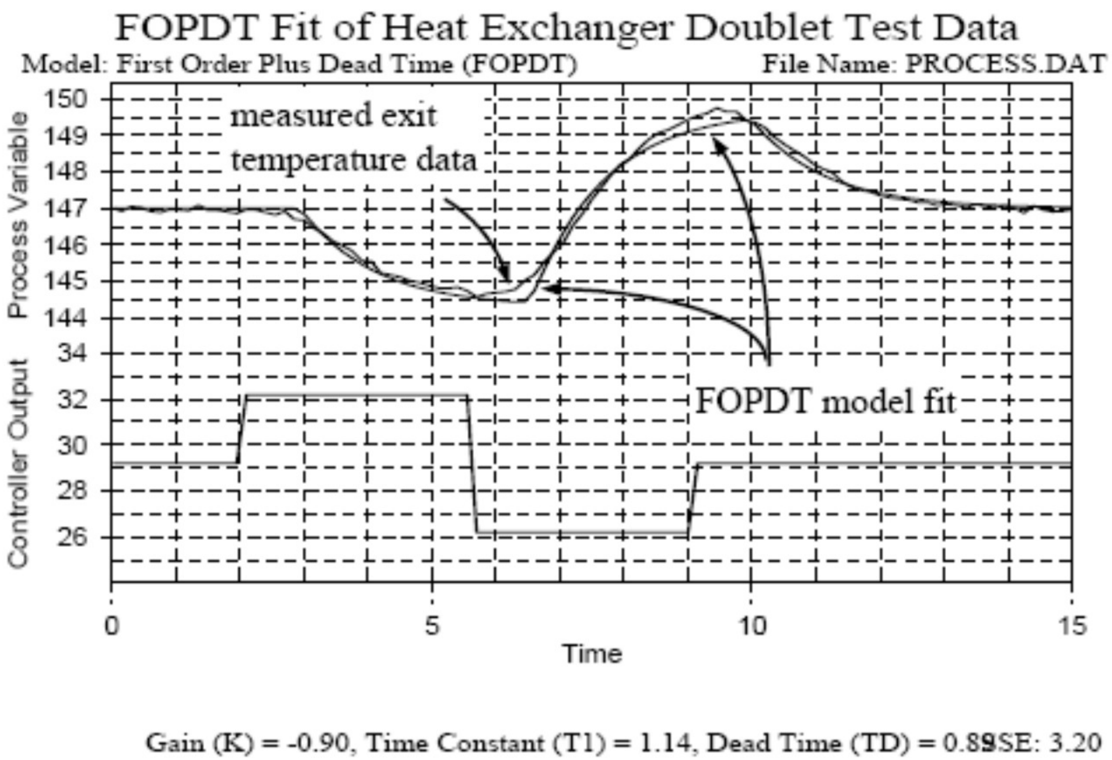


Figure 6.6 - Design Tools fit of heat exchanger doublet test data using a FOPDT model

Fit results in values for K_p, τ_p, and θ_p

$$\tau_p \frac{dy}{dt} + y = K_p\ u(t - \theta_p)$$

Controller Design Using Closed Loop Data

- Operations may not open an existing loop for controller design, so closed loop dynamic testing required
- In theory, closed loop testing can produce data that reflects the character of the controller as well as that of the process
- In practice this rarely is a problem
- For closed loop studies, dynamic data is generated by stepping, pulsing or otherwise perturbing the set point
- The controller must be tuned aggressive enough so that the changing controller output forces the measured process variable to move more than ten times the noise band

Do Not Model Disturbance Driven Data!
(for controller design)

- A controller uses the FOPDT model to understand how its output signal affects the measured process variable
- So test data must contain measured process variable dynamics that have been forced by the controller output
- Disturbance events that occur during data collection will degrade accuracy and hence usefulness of the FOPDT model

Comparison of Manual vs. Automated Fits

	← Open Loop Data →		Closed Loop Data
	Graphical Analysis Of Step Test	*Design Tools* Doublet Fit	*Design Tools* Fit of Set Point Doublet
Process Gain, K_P (°C/%)	–0.86	–0.90	–0.86
Time Constant, τ_P (min)	1.0	1.1	1.2
Dead Time, θ_P (min)	0.3	0.9	1.0
Sum of Squared Errors (SSE)	44.1	3.2	5.4
ITAE Controller Gain, K_C (%/°C)	–2.1	–0.7	–0.7

Table 6.7 – Comparing FOPDT models for heat exchanger

FOPDT Fit of Underdamped Process

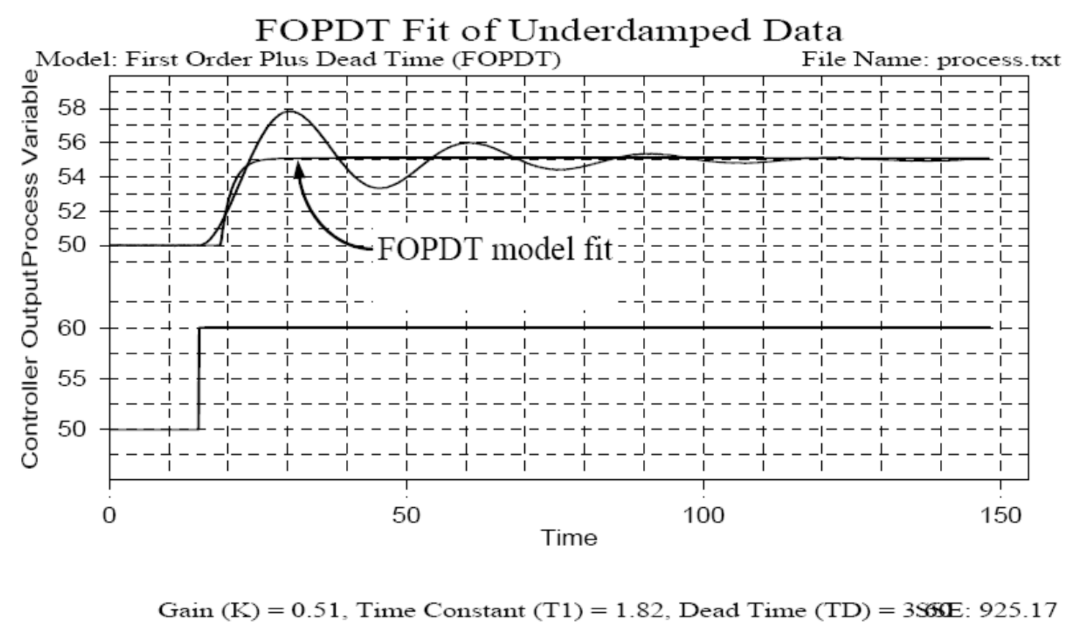


Figure 6.14 - FOPDT model fit of an underdamped process

- Fit looks bad
  - No oscillations predicted
- FOPDT parameters used in correlations to get tuning parameters
  - Good control parameters!
- Reason:
  - Time delay modeled
  - Initial time response modeled
    - Direction of response as well
  - Gain (ultimate response to controller output) modeled

Inverse Response

The measured process variable first moves in one direction before it ultimately responds to steady state in the opposite direction

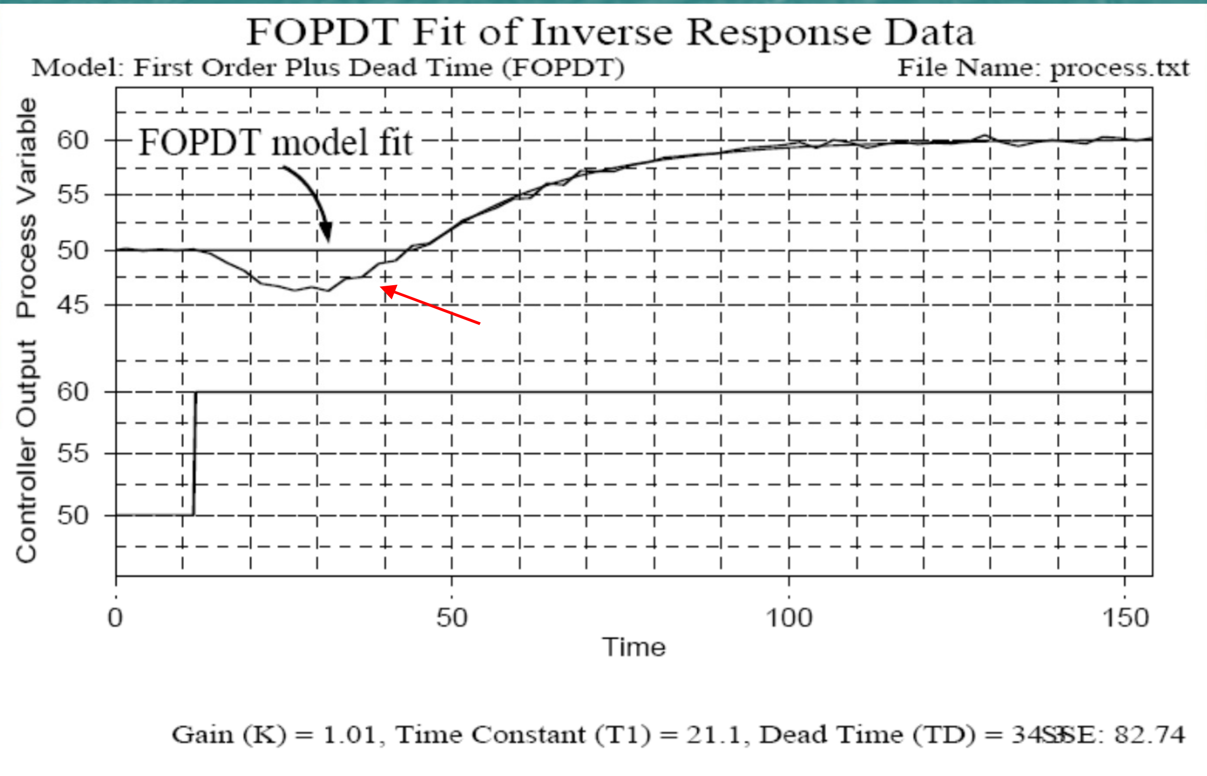


Figure 6.15 - FOPDT model fit of an inverse process

Sometimes teenagers act this way (or spouses)!

Let’s Do It in Control Station!