Understanding Dynamic Process Behavior

- To learn about the dynamic behavior of a process, analyze measured process variable test data
- Process variable test data can be generated by suddenly changing the controller output signal
- Be sure to move the controller output far enough and fast enough so that the dynamic behavior of the process is clearly revealed as the process responds
- The dynamic behavior of a process is different as operating level changes (nonlinear behavior) so collect process data at normal operating levels (design level of operation)

Modeling Dynamic Process Behavior

- The best way to understand process data is through modeling
- Modeling means fitting a first order plus dead time (FOPDT) dynamic process model to the data set:
  \[ \tau_p \frac{dy(t)}{dt} + y(t) = K_p u(t - \theta_p) \]
  where:
  - \( y(t) \) is the measured process variable
  - \( u(t) \) is the controller output signal
- The FOPDT model is low order and linear so it can only approximate the behavior of real processes

- When a first order plus dead time (FOPDT) model is fit to dynamic process data
  \[ \tau_p \frac{dy(t)}{dt} + y(t) = K_p u(t - \theta_p) \]
  - The important parameters that result are:
    - Steady State Process Gain, \( K_p \)
    - Overall Process Time Constant, \( \tau_p \)
    - Apparent Dead Time, \( \theta_p \)

- Tuning of controller means selecting the parameters for "best" operation
- FOPDT model of dynamics of the process are used
  - \( K_p \)
  - \( \tau_p \)
  - \( \theta_p \)
- See correlations
- This "Tuning Guide" is located in the back of the pdf file for the Practical Process Control book

The FOPDT Model is All Important

- model parameters \( (K_p, \tau_p, \theta_p) \) are used in correlations to compute initial controller tuning values
- sign of \( K_p \) indicates the action of the controller
  - \( +K_p \rightarrow \) reverse acting; \( -K_p \rightarrow \) direct acting
- size of \( \tau_p \) indicates the maximum desirable loop sample time (be sure sample time \( T \leq 0.1 \tau_p \))
**Step Test Data and Dynamic Process Modeling**

- Process starts at steady state
- Controller output signal is stepped to new value
- Measured process variable allowed to complete response

**Process Gain From Step Test Data**

- $K_p$ describes how much the measured process variable, $y(t)$, changes in response to changes in the controller output, $u(t)$
- A step test starts and ends at steady state, so $K_p$ can be computed from plot axes

\[
K_p = \frac{\text{Steady State Change in the Measured Process Variable, } \Delta y(t)}{\text{Steady State Change in the Controller Output, } \Delta u(t)}
\]

where $\Delta u(t)$ and $\Delta y(t)$ represent the total change from initial to final steady state
- A large process gain means the process will show a big response to each control action

**Overall Time Constant From Step Test Data**

- $\tau_p$ describes how fast the measured process variable, $y(t)$, responds to changes in the controller output, $u(t)$
- $\tau_p$ is how long it takes for the process variable to reach 63.2% of its total change, starting from when the response first begins

**$K_p$ for Gravity Drained Tanks**

- $K_p = \frac{\Delta y}{\Delta u} = \frac{2.86 - 1.93}{80 - 90} \text{ m/m} = 0.095 \text{ m/m}$

Steady state process gain has a:
- size (0.095), sign (+0.095), and units (m/m)

**$\tau_p$ for Gravity Drained Tanks**

1) Locate where the measured process variable first shows a clear initial response to the step change – call this time $t_{Ystart}$
- From plot, $t_{Ystart} = 9.6 \text{ min}$

2) Locate where the measured process variable reaches $y_{63.2}$ or where $y(t)$ reaches 63.2% of its total final change
- Label time $t_{Y63.2}$ as the point in time where $y_{63.2}$ occurs

**Gravity Drained Tanks - Open Loop Step Test**
Apparent Dead Time From Step Test Data

- $\theta_P$ is the time from when the controller output step is made until when the measured process variable first responds
- Apparent dead time, $\theta_P$, is the sum of these effects:
  - transportation lag, or the time it takes for material to travel from one point to another
  - sample or instrument lag, or the time it takes to collect analyze or process a measured variable sample
  - higher order processes naturally appear slow to respond

- Notes:
  - Dead time must be positive and have units of time
  - Tight control in increasingly difficult as $\theta_P > 0.7 \tau_P$
  - For important loops, work to avoid unnecessary dead time

Processes Have Time-Varying Behaviors

- The predictions of a FOPDT model are constant over time
- But real processes change every day because
  - surfaces foul or corrode
  - mechanical elements like seals or bearings wear
  - feedstock quality varies and catalyst activity drifts
  - environmental conditions like heat and humidity change
- So the values of $K_P$, $\tau_P$, $\theta_P$ that best describe the dynamic behavior of a process today may not be best tomorrow
- As a result, controller performance will degrade with time and periodic retuning may be required
Gravity Drained Tanks is Nonlinear

Nonlinear Behavior of Gravity Drained Tanks

Model Test Value Plots (Units: m, %)

A controller should be designed for a specific level of operation!