Class 4

Dynamic Process Behavior

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

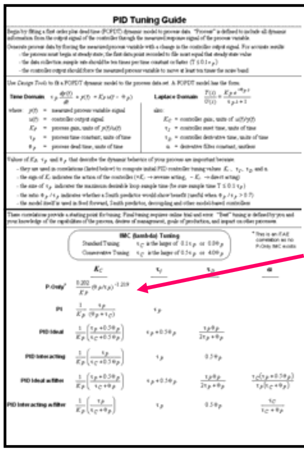
- The FOPDT model is low order and linear so it can only approximate the behavior of real processes

Modeling Dynamic Process Behavior

- 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, τ_P
  - Apparent Dead Time, θ_P



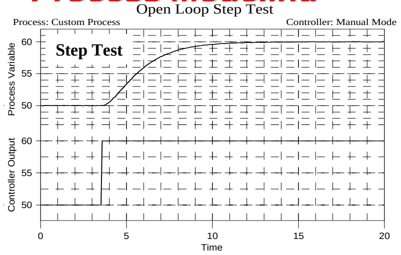
PID Tuning Guide

- Tuning of controller means selecting the parameters for "best" operation
- FOPDT model of dynamics of the process are used
  - K_p
  - τ_p
  - θ_p
- See correlations
- This "Tuning Guide" is located in the back of the pdf file for the Practical Process Control book
- This is a place to start (close but not best)

The FOPDT Model is All Important

- model parameters (K_P, τ_P and θ_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 τ_P indicates the maximum desirable loop sample time (be sure sample time $T \le 0.1\,\tau_P$)

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

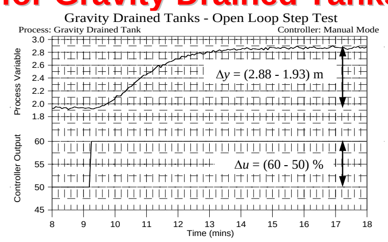
- K_P describes how much the measured process variable, $y(t)$, changes in response to changes in the controller output, $u(t)$
- A step test starts and ends at steady state, so K_P can be computed from plot axes

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

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

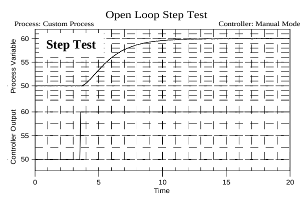
K_P for Gravity Drained Tanks



$$K_P = \frac{\Delta y}{\Delta u} = \frac{2.88 - 1.93 \text{ m}}{60 - 50\,\%} = 0.095 \frac{\text{m}}{\%}$$

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

Overall Time Constant From Step Test Data



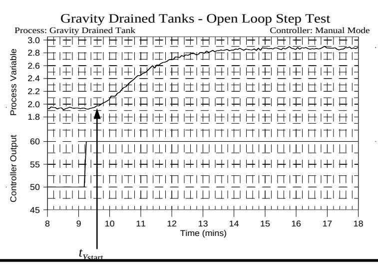
Time Constant τ_P describes how fast the measured process variable, $y(t)$, responds to changes in the controller output, $u(t)$

τ_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

τ_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}

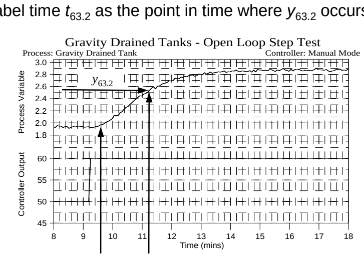
From plot, t_{Ystart} = 9.6 min



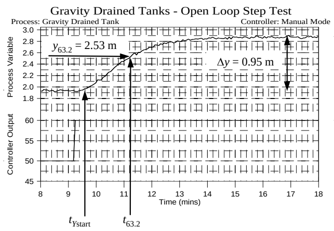
τ_P for Gravity Drained Tanks

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 $t_{63.2}$ as the point in time where $y_{63.2}$ occurs



τ_P for Gravity Drained Tanks

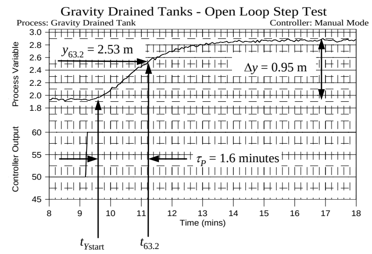


- $y(t)$ starts at 1.93 m and shows a total change Δy = 0.95 m
- $y_{63.2}$ = 1.93 m + 0.632(Δy)
  = 1.93 m + 0.632(0.95 m) = 2.53 m
- $y(t)$ passes through 2.53 m at $t_{63.2}$ = 11.2 min

τ_P for Gravity Drained Tanks

- The time constant is the time difference between t_{Ystart} and $t_{63.2}$
- Time constant must be positive and have units of time

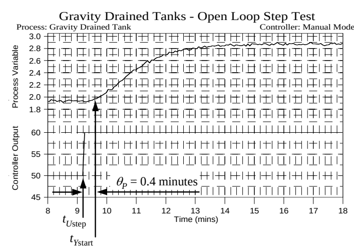
From the plot: $\tau_P = t_{63.2} - t_{Ystart}$ = 11.2 min – 9.6 min = 1.6 min



Apparent Dead Time From Step Test Data

- θ_P is the time from when the controller output step is made until when the measured process variable first responds
- Apparent dead time, θ_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

θ_P for Gravity Drained Tanks



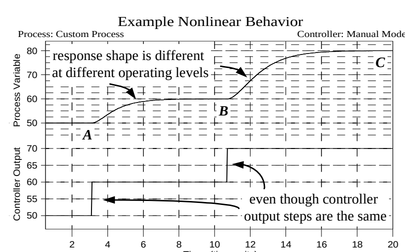
$$\theta_P = t_{Ystart} - t_{Ustep}$$
$$= 9.6 \text{ min} - 9.2 \text{ min}$$
$$= 0.4 \text{ min}$$

Processes Have Time-Varying Behaviors

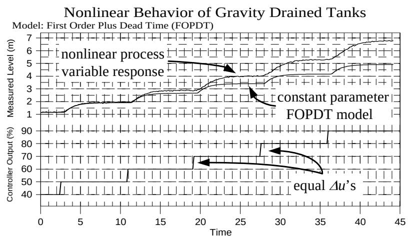
- The predictions of a FOPDT model are constant over time
- But real processes change every day because
  - surfaces foul or corrode
  - mechanical elements like seals or bearings wear
  - feedstock quality varies and catalyst activity drifts
  - environmental conditions like heat and humidity change
- So the values of K_P, τ_P, θ_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

Processes Have Nonlinear Behaviors

- The predictions of a FOPDT model are constant as operating level changes
- The response of a real process varies with operating level



Gravity Drained Tanks is Nonlinear



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