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The Learn Control Systems - Online Process Plant

Tuning of Process Controllers

Many undergraduate engineering programs teach the Ziegler-Nichols tuning methods, developed by John G. Ziegler and Nathaniel B. Nichols in the 1940s. This tuning method has a large controller gain and short integral time, and sometimes creates process oscillations, which are not good for most chemical engineering applications. As a result, many process control engineers resort to tuning by feel. Individual control loops are tuned as fast as possible without disrupting the upstream and downstream control loops.

However, by tuning only individual loops, the overall process performance and the ability to recover from disturbances are reduced. When a process has been tuned by feel, console operators often need to put controllers into manual operation to settle the process down after a major process disturbance.

Automatic process control attenuates disturbances and maintains control of the process variables to match desired set point and appropriate tuning enables this capability. This section describes process controller basics, and details a step-by-step process for open and closed control loop tuning.

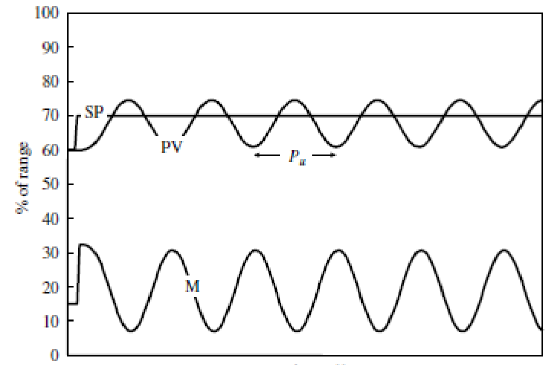
Process controllers can be tuned in two ways, open loop and closed loop. In open loop the controller is put into manual mode, opening the measurement feedback loop. A change is made in the output to the final correction device and a process reaction curve is read to tune the controller. In closed loop the controller uses the feedback signal in automatic mode. Gain is increased until a sustained oscillation is achieved. The plot of the oscillation is then used to retrieve the tuning parameters.

We will now look at two different methods for tuning a controller, the Ultimate Gain (Continuous Cycling), and Process Reaction Curve (Step Response) methods. We will use the Ziegler-Nichols method but the Cohen-Coon or Integrated Absolute Error method could be used instead.

Closed Loop Tuning of the Controller (Ziegler-Nichols)

Tuning Based on the Ultimate Gain Method (Ziegler-Nichols)

Essentially, the tuning method works by oscillating the process. Turn off the Integral mode or set time to zero (0.000) and turn off the derivative mode (0.000). Increase the gain of the controller and make a slight set-point change. Repeat the process and gradually increase the gain of the controller each time, until a sustained oscillation is achieved as shown in the following figure.



Sustained oscillation

This is called the *ultimate gain* (Ku). It is the gain of the controller necessary to make the process sustain oscillation. The proportional band gain (PB) is the reciprocal of the ultimate gain (Ku).

Tune the controller by entering the new Ziegler-Nichols values from the calculations in Table 1 below.

The table values are to be entered as ***gain***. If you need to convert gain to proportional band, then PB=1/Ku and Ku=1/PB.

Proportional band = 1/Gain   Gain = 1/Proportional band

The period of the oscillation, equals Pu in minutes. The time calculation will be entered as ***minutes per repeat*** for Integral time and Derivative time as ***minutes***.

Remember when entering the Integral time:

Minutes per repeat = 1/ Repeats per minute
Repeats per minute = 1/ Minutes per repeat
Proportional band is typically displayed as %, for example: 0.50 Kc = 200% PB, 2.00 Kc = 50% PB

Verify your controller's settings and nomenclature of the settings.

Table 1 - Tuning parameters for the closed loop Ziegler-Nichols method

Controller type	Gain, Kc	Integral Time, TI	Derivative time, TD
P	$0.5K_u$		
PI	$0.45K_u$	$\frac{P_u}{1.2}$	
PID	$0.6K_u$	$\frac{P_u}{2}$	$\frac{P_u}{8}$

The Controller Tuning Parameters

First convert P_U from seconds into minutes!

Example, say P_U was 13 seconds, then P_U equals (13 sec * 1 min / 60 sec). Then P_U equals 13 / 60 = 0.2167 minutes.

K_U = Ultimate gain … The gain necessary to cause the steady oscillation of the system
K_C = Controller gain … divide by 2 to be conservative
K_I = 1 / T_I (Integral) … 1 / minutes
K_D = T_D (Derivative) … minutes

PID Implementation Note:

The Allen-Bradley PID controller has “Dependent” and “Independent” PID calculation

The Online Process Plant use the “Dependent” equation

$$CV_n = CV_{n\text{-}1} + K_C \left(\Delta E + \frac{1}{60T_I} E\Delta t + 60T_D \frac{E_n - 2E_{n-1} + E_{n-2}}{\Delta t} \right)$$

- *CV* = Control variable
- *E* = Error in percent of span
- Δt = Update time in seconds used by the loop
- K_C = Controller gain
- T_D = Derivative time constant in minutes
- T_I = Integral time constant in minutes per repeat. In other words, it will take TI minutes for the integral term to repeat the action of the proportional term in response to a step change in error. Note that a larger value of TI causes a slower integral response.

Open-loop Tuning of the Controller (Ziegler-Nichols)

Tuning Based on the Process Reaction Curve

In process control, the term ’reaction curve’ is sometimes used as a synonym for a step response curve. Many chemical processes are stable and well damped. For such systems the step response curve can be approximated by a first-order-plus-dead time (FOPDT) model. It is relatively straightforward to fit the model parameters to the observed step response. Look at the reaction curve below.

Essentially, the tuning method works by manually causing a step change in the process. This is accomplished by putting the controller in manual and forcing an output change of the controller. Record the step change process reaction curve on the chart recorder and follow the setup instructions below.

1. Locate the point where the curve stops curving upwards from the left and bottom and starts to complete the curve up to the right and settles at a new process measurement level. This will be about half way up the reaction curve. It is the inflection point.

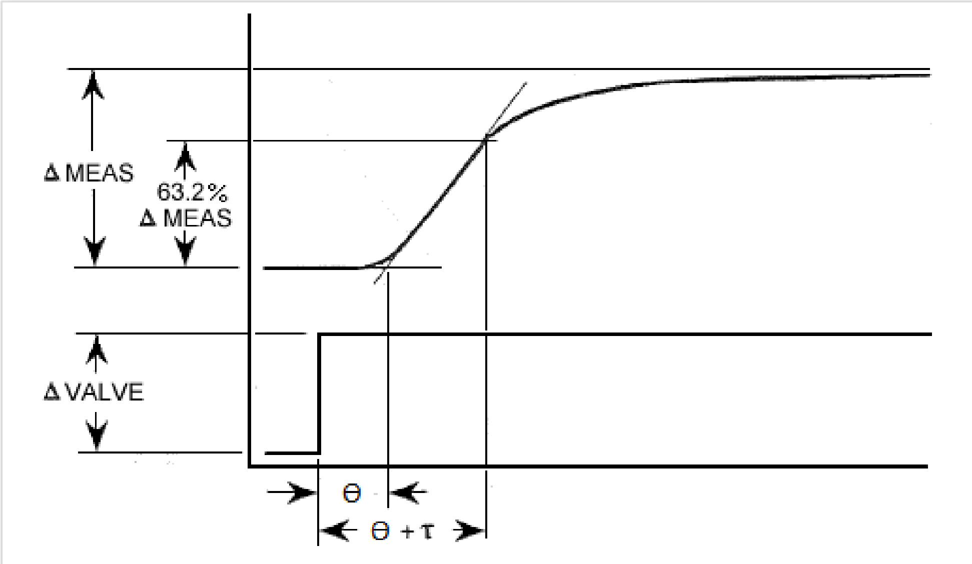
2. Draw an asymptote line tangential to the point of the inflection. Where the asymptote line crosses the bottom of the process reaction curve, the previous output is assumed to be zero (it is the measurement before the set-point change was made, which is now zero to the measurement of the process change). It may be equal to 6 inches, but set it to a live zero. The time between the start of the output step change and the start of the asymptote line at the live zero of the process measurement, is the apparent time delay or dead time (T_D) of the system.

   When the asymptote line reaches the steady state value of 63.2% of Delta Measurement, the time difference between the end of the dead time measurement (T_D) and the end of the 63.2% of delta measurement, is called the *time constant* for the process (τ). Draw a line straight down from the 63.2% point to the live zero line. These are the values of (τ), the time constant of the process, and (Θ), the dead time of the process.

3. The gain of the system K_P (the slope of the asymptote line) is given by:

$$K_P = \text{Process gain} \ldots \left(\frac{\Delta\text{measurement}}{\Delta\text{valve change}}\right) = \left(\frac{\Delta\text{measurement}}{\Delta\text{controller output}}\right) = \left(\frac{\text{output of the system}}{\text{input to the system}}\right)$$

Typical Process Reaction Curve for Tuning a Controller in Open-Loop



Just measure the minor divisions of the treading chart and divide the change in measurement, by the change in output. Calculate the time constant (τ) and the deadtime (Θ) and convert seconds into minutes , if the measurement is not already in minutes on the trending chart. Then just use Table 2 to calculate Kc, TI and TD, for the type of control to implement (P, PI, or PID).

Example 1:

You make a manual mode change in the valve output. It the chart shows the valve moved by four (4) minor divisions. Then the process measurement changes by three (3) division before setting out to steady state.

The process gain (K_P), equals 3/4 or (0.75).

Example 2:

You make a manual mode change in the valve output. It the chart shows the valve moved by four (4) minor divisions. Then the process measurement changes by three (6) division before setting out to steady state.

The process gain (K_P), equals 6/4 or (1.50).

Table 2 - Tuning Parameters for the Open-Loop Method (Ziegler-Nichols)

Controller Type	Gain, Kc	Integral time, TI	Derivative time, TD
P	$\frac{\tau}{K_P\ \theta}$		
PI	$\frac{0.9\ \tau}{K_P\ \theta}$	$\frac{\theta}{0.3}$	
PID	$\frac{1.2\ \tau}{K_P\ \theta}$	$\frac{\theta}{0.5}$	0.5θ

Note: This table of tuning parameters has (τ = lag time) in the equation for a lag time of 63.2% of delta process measurement, (Θ = Dead Time) of the process.

The Controller Tuning Parameters

First convert τ and Θ from seconds into minutes!

Example, say τ was 10 seconds, then τ equals (10 sec * 1 min / 60 sec). Then τ equals 10 / 60 = 0.1667 minutes.
Example, say Θ was 5 seconds, then Θ equals (5 sec * 1 min / 60 sec). Then Θ equals 5 / 60 = 0.0833 minutes.

K_P = Process gain … $\left(\frac{\Delta\text{measurement}}{\Delta\text{valve change}}\right)=\left(\frac{\Delta\text{measurement}}{\Delta\text{controller output}}\right)=\left(\frac{\text{output of the system}}{\text{input to the system}}\right)$
K_C = Controller gain … divide by 2 to be conservative (smaller gains reduce overshoot)
T_I = (Integral) … minutes / repeat
T_D = (Derivative) … minutes

PID Implementation Note:

The Allen-Bradley PID controller has “Dependent” and “Independent” PID calculation

The Online Process Plant use the “Dependent” equation

$$CV_n = CV_{n\text{-}1} + K_C \left(\Delta E + \frac{1}{60T_I} E\Delta t + 60T_D \frac{E_n - 2E_{n-1} + E_{n-2}}{\Delta t} \right)$$

- CV = Control variable
- E = Error in percent of span
- Δt = Update time in seconds used by the loop
- K_C = Controller gain
- T_D = Derivative time constant in minutes
- T_I = Integral time constant in minutes per repeat. In other words, it will take TI minutes for the integral term to repeat the action of the proportional term in response to a step change in error. Note that a larger value of TI causes a slower integral response.

Open-loop Tuning of the Controller (Cohen-Coon)

Tuning Based on the Process Reaction Curve Cohen-Coon

The Cohen-Coon tuning method is a more aggressive tuning of the controller. The open loop tuning parameters are listed in Table 3.

Typical Process Reaction Curve for Tuning a Controller in Open-Loop

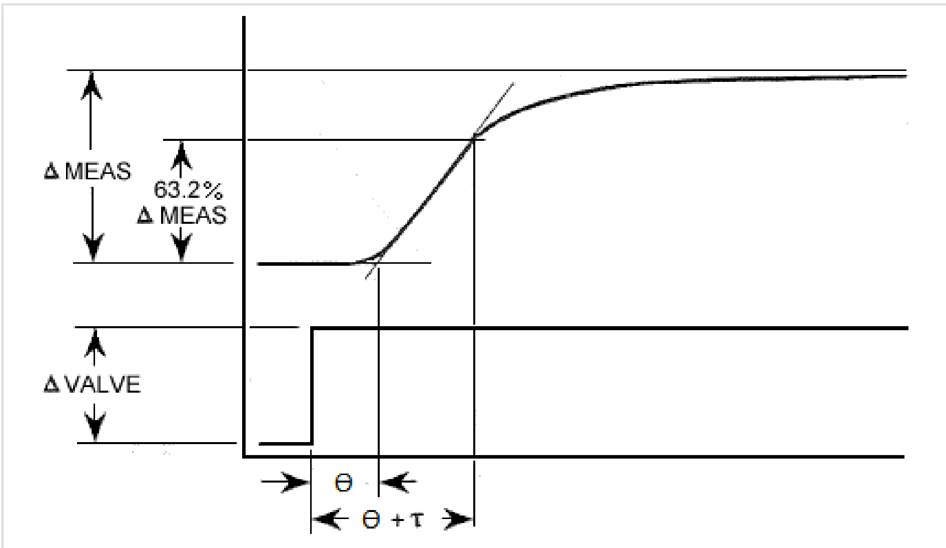


Table 3 - Tuning Parameters for the Open-Loop Cohen-Coon Method

Controller Type	Gain, Kc	Integral time, TI	Derivative time, TD
P	$\frac{1}{K_P}\frac{\tau}{\theta}\left(1+\frac{\theta}{3\tau}\right)$		
PI	$\frac{1}{K_P}\frac{\tau}{\theta}\left(\frac{9}{10}+\frac{\theta}{12\tau}\right)$	$\frac{\theta\left[30+3(\theta/\tau)\right]}{9+20(\theta/\tau)}$	
PID	$\frac{1}{K_P}\frac{\tau}{\theta}\left(\frac{4}{3}+\frac{\theta}{4\tau}\right)$	$\frac{\theta\left[32+6(\theta/\tau)\right]}{13+8(\theta/\tau)}$	$\frac{4\theta}{11+2(\theta/\tau)}$

Note: This table of tuning parameters has (τ = lag time) in the equation for a lag time of 63.2% of delta process measurement, (Θ = Dead Time) of the process.

The Controller Tuning Parameters

First convert τ and Θ from seconds into minutes!
Example, say τ was 10 seconds, then τ equals (10 sec * 1 min / 60 sec). Then τ equals 10 / 60 = 0.1.667 minutes.
Example, say Θ was 5 seconds, then Θ equals (5 sec * 1 min / 60 sec). Then Θ equals 5 / 60 = 0.0833 minutes.

K_P = Process gain … $\left(\frac{\Delta\text{measurement}}{\Delta\text{valve change}}\right)=\left(\frac{\Delta\text{measurement}}{\Delta\text{controller output}}\right)=\left(\frac{\text{output of the system}}{\text{input to the system}}\right)$
K_C = Controller gain … divide by 2 to be conservative (smaller gains reduce overshoot)
T_I = (Integral) … minutes / repeat
T_D = (Derivative) … minutes

Tuning The Online Process Plant (Open Loop Method)

Hands On - Online Process Plant Tuning Steps

Step 1

Reference figure 1 below for the following instructions. Start the plant up in PID mode and select a level of 5.50 inches and press enter. ***Put the load valve at 80% load, to give the plant more gain***. With less flow out of the process tank, it gives a process gain of about four (4). Let the level settle out, it will oscillate around 5.50 inches, setting out by plus and minus 0.15 inches. Try to catch the PV (Process Variable) at exactly 5.50 inches and put the Level Control Valve (LCV-100) in manual mode. Toggle the Automatic button to Manual.

Set the Level Control Valve (LCV-100), to 50.00% and press enter. Let the CV (Control Variable) and PV (Process Variable) settle out and straight line out on the trend chart.

Step 2

Set the Kc, Ti and Td, in the tuning parameter box, to 0.000 to clear all settings and press enter. Make a 5% change in the Level Control Valve (LCV-100), from 50.00% to 55.00%. Note: Do not increase to 60.00%. The fluid coming into the tank will be too great and the level will increase until the pump shuts down on high-high level. Let the new PV (Process Variable) settle out and straight line out on the trend chart. When the lines are straight again, press Pause Trend to pause the trend chart and get the measurements.

Step 3

Calculate the deadtime (Θ) in seconds. Then calculate the time constant (τ) in seconds. This is the time when the PV started rising, to when it reached steady state (straight lined again). The time constant is at 63.2% of rise time. This can be easily calculated by taking the rise time from beginning of the rise, to straight line and dividing the time in seconds by 5. There are five (5) time constants until setting time.

First convert τ and Θ from seconds into minutes!
Example, say τ was 30 seconds, then τ equals (30 sec * 1 min / 60 sec). Then τ equals 30 / 60 = 0.5 minutes.
Example, say Θ was 2 seconds, then Θ equals (2 sec * 1 min / 60 sec). Then Θ equals 2 / 60 = 0.0333 minutes.

Calculate the K_P (Process gain). The CV - valve changed by 5%. The PV - process variable changes by approximately 20%.

K_P = Process gain … $\left(\frac{\Delta\text{measurement}}{\Delta\text{valve change}}\right) = \left(\frac{\Delta\text{measurement}}{\Delta\text{controller output}}\right) = \left(\frac{\text{output of the system}}{\text{input to the system}}\right) = \frac{20}{5} = 4$

Step 4

Calculate the values for P, PI and PID modes. You are finding the values:

K_C = Controller gain … divide by 2 to be conservative (smaller gains reduce overshoot)
T_I = (Integral) … minutes / repeat
T_D = (Derivative) … minutes

Table 2 - Tuning Parameters for the Open-Loop Method (Ziegler-Nichols)

Controller Type	Gain, Kc	Integral time, TI	Derivative time, TD
P	$\frac{\tau}{K_P\ \theta}$		
PI	$\frac{0.9\ \tau}{K_P\ \theta}$	$\frac{\theta}{0.3}$	
PID	$\frac{1.2\ \tau}{K_P\ \theta}$	$\frac{\theta}{0.5}$	0.5θ

Values for the Controller Modes…

P - Mode

$$K_C = \frac{\tau}{K_P \ \theta} = \frac{0.5}{4 \bullet \ 0.0333} = 3.75$$

PI - Mode

$$K_C = \frac{0.9 \ \tau}{K_P \ \theta} = \frac{0.9 \ \bullet 0.5}{4 \bullet \ 0.0333} = 3.375$$

$$T_I = \frac{\theta}{0.3} = \frac{0.0333}{0.3} = 0.111$$

PID - Mode

$$K_C = \frac{1.2 \ \tau}{K_P \ \theta} = \frac{1.2 \ \bullet 0.5}{4 \bullet \ 0.0333} = 4.5$$

$$T_I = \frac{\theta}{0.5} = \frac{0.0333}{0.5} = 0.067$$

$$T_D = 0.5\theta = 0.5 \bullet 0.0333 = 0.016$$

Figure 1 - The Online Process Plant Control Panel