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Industry Insight

Control Loop Tuning
in 10 minutes

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CONTENT

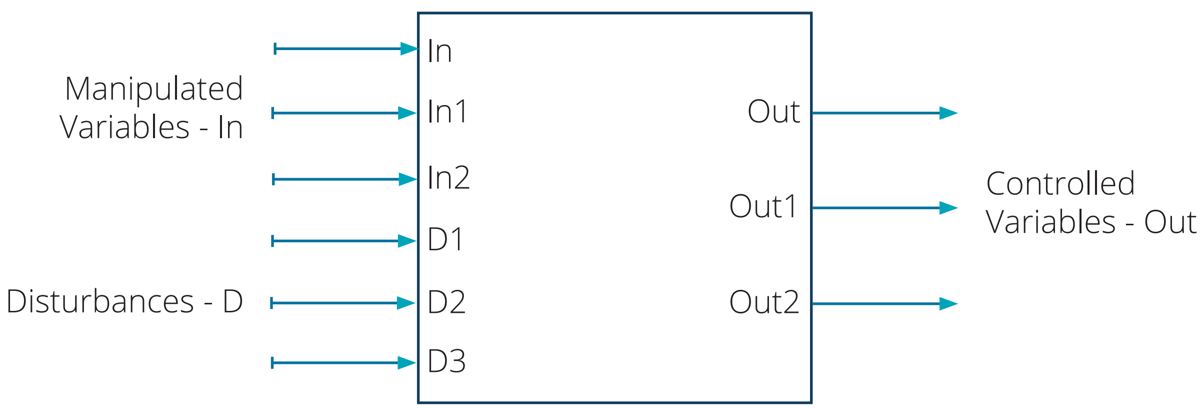
ABSTRACT

Modern industrial process control techniques are highly dependent on control loops. Whether it be pressure, level, flow, or temperature control, defining proper tuning parameters is essential in maintaining control, reducing variability, mitigating process upsets, and maintaining an economical process. A control loop that is properly tuned will reduce product variations, and raw material/energy waste that leads to lower operating costs. For example, extending equipment life by reducing unnecessary equipment oscillation, thus reducing maintenance cost. Another real-world gain is in production gain. Company X tuned the NG compressor which allowed them to increase the compressor RPM by 2%, which resulted in more than $1MM/year.

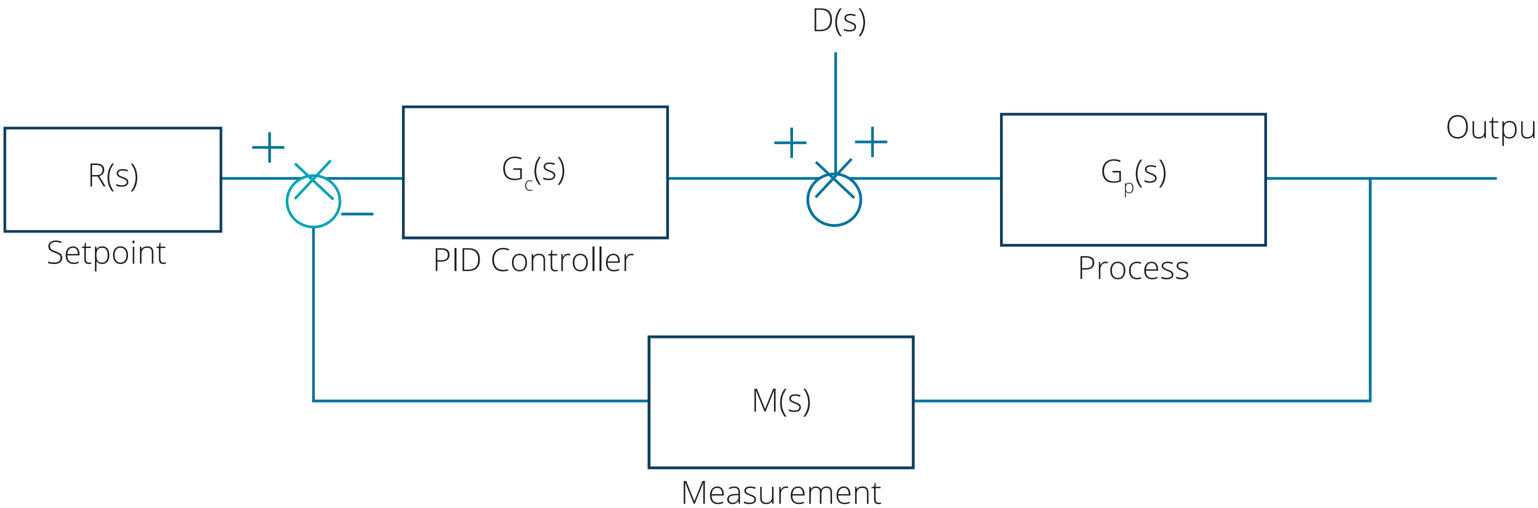
BRIEF PROCESS CONTROL BACKGROUND

Process systems consist of three main factors: manipulated variables, disturbances, and controlled variables (see Figure 1). Disturbances enter the process system; this drives the controlled variables away from the desired value. The control system must adjust the manipulated variables, so the desired value is maintained, this is where the process control system is most important. The process control system consists of four elements: process, measurement, evaluation, and control (see Figure 2). The figure also shows disturbances, without the disturbance, there would be no need for a control system. In general, a process will consist of many pieces of equipment, with its own process dynamics allowing to control or neglect certain dynamics in the control scheme. In order to measure process dynamics, a measurement device must be in place. Transducers typically take on this role for measurement, converting physical parameters to an electrical or pneumatic signal.

Process Control Variables - Figure 1



Disturbances - Figure 2



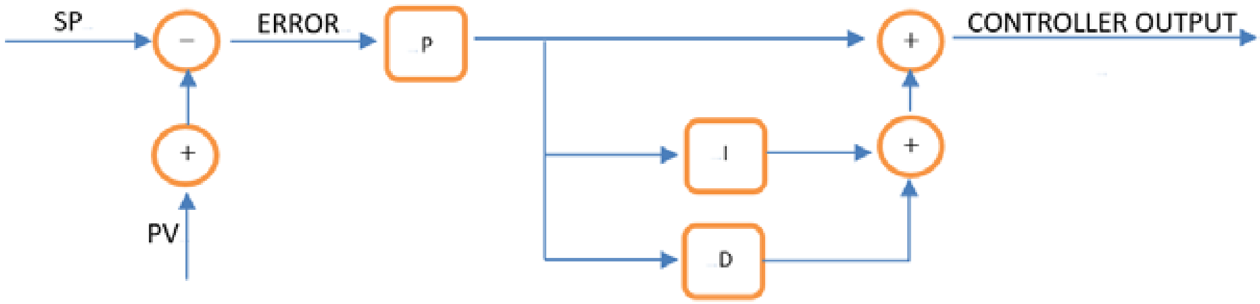
The evaluation examines the measured value and compares it with the desired value or set point. Once the comparative is completed, the difference of the two signals are input into a controller where the evaluation is completed. The control element is a device that exerts a direct influence on the process.

The control loop in question needs to be characterized prior to determining best tuning parameters. The three main methods of control are proportional only (P), proportional plus integral (PI), proportional plus integral plus derivative (PID). Most modern control system have an auto-tune feature. Autotune features reduce human error introduced by calculations or tuning by hand. A basic plant control loop involves a controller output to a device such as a valve. This is the manipulated variable. Some form of instrumentation provides feedback to the controller. This is the process variable. The manipulated variable responds to the process variable through relationships to reach the setpoint variable. Tuning allows the controller to do this in a manner which reduces error.

There are three main types of PID algorithms and you can determine which algorithm is used by consulting your controller manual. These are known as Standard, Parallel, and Series. In addition, if the derivative of these algorithms is taken, they can be represented as velocity equations, or second order differential equations. In other words, the velocity algorithm allows for a control output to be based on the change in position from it's starting position, rather than controller output to a final position. When speaking of integration of errors, it is possible that the accumulation could become large enough to command the controller output to something that is not physically possible with, say, a valve or a motor. A valve can only open/close between its physical limits. If the error continually accumulates, it could offset the controller output to something not physically possible, and the control loop would not respond properly. This concept is called "windup" and modern controllers offer "anti-reset windup" parameters.

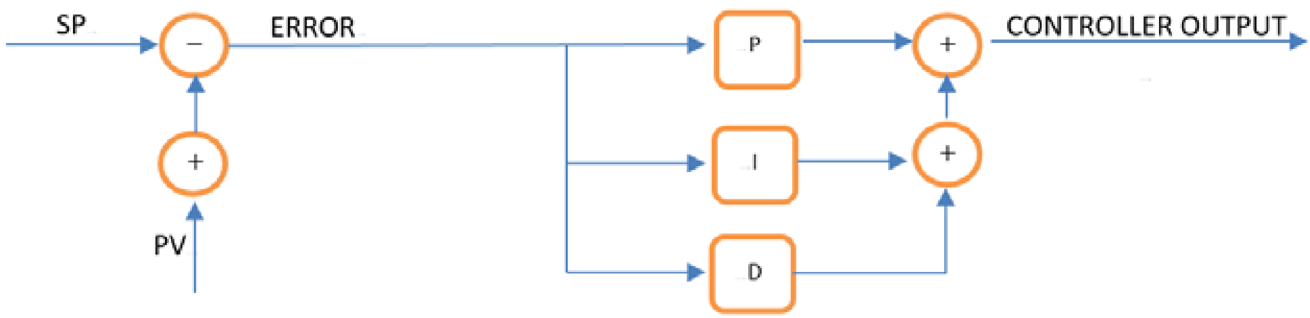
The Standard (Ideal) Algorithm: Cohen-Coon tuning methods. Same as series without derivative. Works well with fixes such as output limits.[1]

$$Controller\ Output = K_c\left[e + \frac{1}{T_i}\int edt\right] + e + K_i\int edT + K_d\frac{dE}{dt}$$



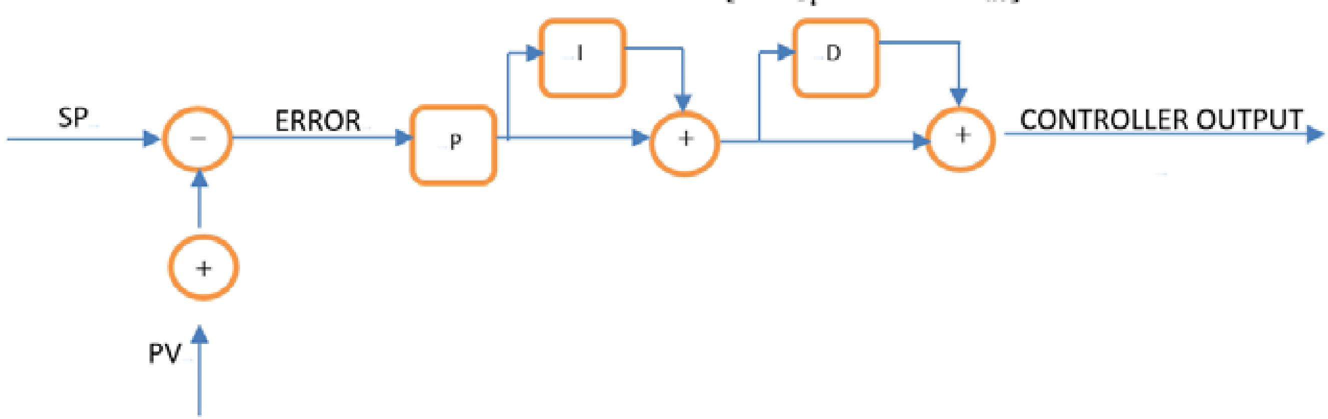
The Parallel Algorithm: Avoid this algorithm.[1]

$$Controller\ Output = K_p + e + K_i\int edt + K_d\frac{dE}{dt}$$



The Series Algorithm: The oldest algorithm. PID parameters affect each other. Used with Ziegler-Nichols. Works well with output limits, etc.[1]

$$Controller\ Output = K_c\left[e + \frac{1}{T_i}\int edt + T_d\frac{dE}{dt}\right]$$



For a simple 1st order process, we want to define the time dependent relationship between the change in output and the change in process variable. This can be done by doing a small step change by placing the controller in manual and increasing or decreasing the output. Since the change in output is defined, we would look at the process response curve to see how much the process variable changed and how long it took. The process gain can be defined as the ratio of the change in PV and the change in controller output or Kp = Δ PV / Δ Output. The process time constant can be approximately defined as $\pi_p = \Delta t / 4$, which approximately correlates to the time it takes to reach 63.2% of the total PV change.

DEFINITIONS

Here are several key definitions used throughout this white paper to establish a common understanding of control loop tuning concepts. These terms provide a foundation for the methods, discussions, and examples that follow.

1 Controlled Variable

The parameter in a control loop that the controller is attempting to keep at a setpoint.

2 Dead Time

The delay after a SP change before a change in PV due to controller action.

3 Disturbance

An unanticipated change to the value of a process variable caused by such things as a SP change, fluctuating temperature due to weather conditions, flow changes due capacity issues, etc.

4 K_c

The value that the error is multiplied by to determine controller output or the "proportional gain".

5 K_p

The process gain.

6 Manipulated Variable

A parameter, such as valve output, that is changed in a control loop to elicit a response in a controlled variable.

7 System Error

The numerical difference between the controlled variable and the setpoint (SP-PV).

8 T_d

Derivative time.

9 T_i

"Reset" or integral time.

10 Tuning

Adjusting the gain, integral time, and derivative time of a controller to achieve the best controller response for a control loop under accepted process conditions.

PICK A CONTROLLER MODE

Depending on what type of control loop needs tuning and your controller algorithm, selecting between P, PI, and PID is necessary. The main types of control loops are flow (FC), level (LC), pressure (PC), temperature (TC), and analytical (AC). The following methods are examples for FOPDT (First Order Plus Dead Time) series algorithms.[2]

P Control – Manipulated variable is changed proportionally to the error.

Advantage = Simple

Disadvantage = Offset error at steady state

PI Control – Manipulated variable is changed proportionally with respect to the duration of the error.

Advantage = Eliminates offset

Disadvantage = Less stability

PID Control – Manipulated variable is changed proportionally with respect the duration and rate of change of the error.

Advantage = No offset, fast response

Disadvantage = Hard to tune, derivative control not suited for PV's with inherent disturbances such as flow and level.

DO THE DISTURBANCE TEST DANCE

Once a controller mode has been selected, a simple test can be done to determine the ultimate gain and ultimate period of a response.

Steps of a Disturbance Test

1. **Consult operators to ensure that the process is safe for testing. Don't get thrown out of the control room! If you can't do live tuning, the loop will have to be modelled.**

2. Setup control loop for proportional only control with a small gain such as 0.5.

3. Put the closed control loop in AUTO.

4. Change the setpoint of the control loop by a small amount that will not cause a huge process upset.

5. Adjust the gain until a stable response is achieved. This is the ultimate gain (Ku) A stable response is indicated by fluctuations of equal absolute magnitude at equal periods. If the response is divergent, the gain should be decreased. If the response is convergent or damped, the gain should be increased.

6. Once a stable response curve is obtained, record the ultimate gain (Ku) and the ultimate period (Pu). The ultimate period is the time between "peaks".

DO THE ZIEGLER-NICHOLS (for Series)

Once the ultimate gain and ultimate period are determined, the following simple equations courtesy of Ziegler and Nichols, are time-tested and valuable solutions to find the tuning parameters for a particular control loop.

1. P-only control - $K_c = K_u / 2$

2. PI control - $K_c = K_u / 2.2$, $t_i = P_u / 1.2$

3. PID control - $K_c = K_u / 1.7$, $t_i = P_u / 2$, $t_d = P_u / 8$

IF YOU CAN'T DANCE, JUST STEP... TEST

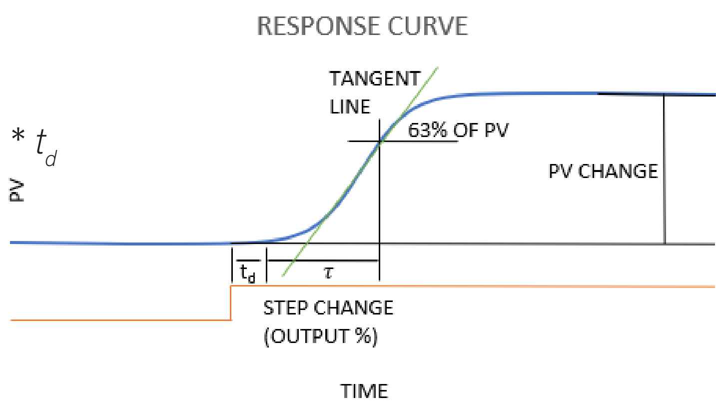
For a First Order Plus Time Delay (FOPTD) process, it is possible to obtain information from an open loop response graph that can be used for tuning.[3]

1. **Consult operators to ensure that control can be manipulated.**
2. Put the loop into MANUAL and give the controller an output that will allow the process to be stable.
3. Allow the control loop to reach steady state.
4. Do the step test by changing the controller output by a small amount that will not wreak havoc on the process.
5. Wait for the process value to stabilize after the change in controller output.
6. Obtain a graph of the controller output and PV.
7. Place the control loop back into its previous mode. If AUTO, set the SP to what it was before the step test. If MANUAL, place the controller output back to where it was before the step test.
8. Determine the change in PV. This is simply the difference between the new steady PV and the PV value before the step-change.
9. Determine the change in controller output. This is simply the difference in the controller output as a result of the step-test.
10. Calculate the process gain as K_p = (Change in PV) / (Change in Controller Output).
11. Determine t_d. This is the "dead time" or the time after the step-change before the PV begins to change.
12. Draw a vertical line at 63% of the total change in PV that intersects the PV curve and the extended horizontal line of the original PV.
13. Determine π. This is the time between when the PV begins to respond and the time it takes the PV to reach 63% of its total value.
14. Use the following equations to obtain the tuning parameters:

P-Only Control - $K_c = \pi / (K_p * t_d)$

PI Control - $K_c = (0.9 * T) / (K_p * t_d)$, $T_i = 3.3 * t_d$

PID Control - $K_c = (1.2 * T) / (K_p * t_d)$, $T_i = 2 * t_d$, $T_d = 0.5 * t_d$



SUMMARY

The methods presented here should work for a variety of typical control scenarios without having to use the "trial and error" tuning method. The disturbance test method is simple but can take more time if you repeatedly must guess the ultimate gain. The step-test method eliminates the need to guess the gain. There are other relationships that can be used such as Cohen-Coon and Pettit and Carr for other tuning algorithms. Taking a small amount of time to properly tune a controller can reap some process and economic benefits.

A smooth-running process lends to a smooth-running business.

REFERENCES

1. https://blog.opticontrols.com/archives/124
2. Hughes, T.A. (2015), Measurement and Control Basics: 5th Edition. International Society of Automation
3. https://blog.opticontrols.com/archives/477

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