There's a common misconception in various corners of the process industries related to advanced process control (APC). When the topic of APC is raised it's not uncommon for practitioners to immediately think of complex fuzzy logic and model predictive solutions. But a broader view of APC also includes advanced applications of the Proportional Integral Derivative (PID) controller. Chief among those APC solutions both used in industry and based on the PID is Cascade Control.
There's a common misconception in various corners of the process industries related to advanced process control (APC). When the topic of APC is raised it's not uncommon for practitioners to immediately think of complex fuzzy logic and model predictive solutions. The cost and configuration of such approaches can be daunting to the average process manufacturer. But a broader view of APC also includes advanced applications of the Proportional Integral Derivative (PID) controller – the technology employed by the plurality of production facilities worldwide to regulate production processes. Chief among those APC solutions both used in industry and based on the PID is Cascade Control.
Cascade Control builds upon the PID’s strengths in order to overcome its known limitations. Specifically, Cascade Control capitalizes on the PID controller’s relatively low cost and ease of configuration. In terms of limitations, Cascade Control addresses the PID’s “one size fits all” regulatory capabilities. The architecture of a PID loop is often characterized as “wire in, wire out” based on its use of a somewhat limited feedback structure. That structure allows the PID to first calculate then correct for error that is induced by disturbances, noise and other process variability. While such an architecture is ideally suitable for processes with rapid dynamics, the single loop PID structure presents challenges for other processes that are less responsive to disturbances. Cascade Control is an advanced application of the PID that can effectively counteract the negative effects of disturbances within slower processes.

The Cascade architecture employs a secondary PID control loop to accelerate an otherwise slow process’ responsiveness to disturbances. In order to affect the desired responsiveness, the secondary loop must demonstrate notably faster dynamics than the primary loop and it must have control over the same Final Control Element (FCE). Due to those faster dynamics the secondary loop is able to respond more quickly to disturbances and thereby maintain better performance. “Nested” within the primary loop, the secondary loop is able to absorb the brunt of disturbances, allowing the primary loop to maintain smoother operation.

Cascade Control enables process engineers to take a less aggressive approach when tuning their primary PIDs. If a single control loop is employed to regulate the performance of a slow responding process, then it would be typical for that controller to be tuned aggressively. The purpose of doing so would be to enable the PID to reject disturbances as rapidly as possible. Through the application of Cascade Control and a secondary PID, however, the primary control loop can be tuned more conservatively which is better for the process’ overall performance. The secondary loop assumes primary responsibility for addressing those same disturbances. In effect, Cascade Control outsources the need for an aggressive response from one controller to another — from the primary loop to a secondary one — and improves the process’ overall ability to reject disturbances.

Methods for tuning cascaded PIDs share a common formula. The following offers a more detailed review of the Cascade Control architecture along with general guidelines for tuning cascaded PIDs.
The Cascade Control Architecture

As noted Cascade Control involves the use of two – or more – PID control loops to enhance a given process’ ability to reject disturbances. Figure 1 on the right illustrates the basic architecture associated with Cascade Control. As shown in the graphic this architecture involves the “nesting” of a secondary control loop inside a primary loop. The secondary loop is configured so that it utilizes the Controller Output of the primary loop as its Set Point. In this fashion the two loops share responsibility for adjustments to the FCE. In order for the process to benefit, the dynamics of the secondary loop must be notably faster than those of the primary loop. A secondary loop that is at least 3-5 times faster than the primary loop allows the process to react quicker with adjustments to the FCE that minimize the negative impact of disturbances.

Tuning Cascaded Control Loops

Tuning cascaded control loops follows the same industry best-practices that are commonly applied when manually tuning individual PID controllers. The approach begins with dynamic testing through the performance of a bump test. Ideally, testing should commence only after the process is considered “quiet” and held steady. A process with steady dynamics will provide the best opportunity for revealing the true cause-and-effect relationship that exists between the Controller Output and the Process Variable. Additionally, it is generally easier to analyze the results and to calculate model parameters when test results both begin and end at a steady-state. While certain software tools have been proven to accurately model noisy and oscillatory bump test data, highly variable test data can include subtleties that are difficult for the human eye to interpret.
Tuning of the Cascade Control architecture begins with the innermost control loop before addressing other, outer loops. In a simple Cascade Control implementation involving two PIDs this involves the tuning of the secondary loop prior to the tuning the primary loop. After the secondary loop is held steady an open-loop bump test should be performed. It is recommended that the size of the bump be at least 4-5 times the noise evident in the process. This assures that the test’s results are clearly distinguishable from the noise. It’s important to note that holding the primary loop steady while tuning the secondary loop is not necessary. A similar closed-loop test can be performed if appropriate tuning software is available.

Once testing is completed parameters should be calculated using trended data and a model that corresponds to the nature of the process (i.e. FOPDT or FOPDT Integrating). For most applications of Cascade Control use of the PI form of the controller is recommended for the inner loop. In instances where the secondary loop’s dynamics are insufficiently fast relative to the primary loop, however, application of the P-Only form of the controller can be considered. In such a situation the P-Only form of the controller has been shown empirically to improve a process’ ability to reject disturbances. While a P-Only controller on the secondary loop will have Offset, the primary loop will systematically apply the necessary corrections. With an appropriate form of the PID in mind, tuning parameters are then calculated through the use of correlations and by applying the appropriate OEM-supplied algorithm.

The primary loop is addressed only after the secondary loop has been tuned satisfactorily. Tuning of the primary loop should begin by placing the secondary loop in automatic or closed-loop. As seen from the “wire-in, wire-out” perspective of the primary controller, the secondary loop’s behavior is part of the primary process’ overall dynamics and should be factored into the calculation of tuning parameters. Once the outer loop is held sufficiently steady a similar bump test should be performed followed by calculation of appropriate model and tuning parameters.

It is a common best-practice to tune the outer loop both conservatively and using either the PI or PID form of the controller. Use of the PID form of the controller should be considered when the primary loop’s dynamics are smooth. Derivative adjusts for Error based on the rate of change in a process. If the primary loop is subject to noise, then Derivative will result in excessive movement of the FCE and accelerate wear and tear with little gain in overall process performance.

Detailed instructions for PID controller tuning can be downloaded from the Control Station website. Simply visit www.controlstation.com and search for “PID Tuning Guide”.

Figure 2 — The First Order Plus Dead-Time (FOPDT) model is commonly used in industry to calculate parameters for process Gain (KP), Time Constant (tP), and Dead-Time (θP).
Loop-Pro: A Standards-Based Approach to PID Controller

Loop-Pro™ Tuner is a standards-based technology ideally suited for tuning cascaded PID controllers. The software is widely recognized for both its ease-of-use and its unique ability to optimize highly complex loops. In six (6) simple steps Loop-Pro guides you through a repeatable procedure that delivers both consistent and superior results. Based on proven best-practices for modeling process dynamics and tuning PID controllers, Loop-Pro fulfills your requirements for optimized Cascade Control.

Repeatable Procedure

» Six step procedure: Connect, Test, Model, Tune, Implement, Report
» Focus modeling on bump test data - avoid disturbance-driven data
» Use built-in heuristics to assess process data resolution and ‘quality

Process Knowledge

» Compare the performance of existing vs. proposed tuning parameters
» Simulate performance of all controller forms (i.e. P-Only, PI, and PID)
» Simplify alignment of loop performance with its control objective
Validation & Documentation

» Facilitate capture of observations and performance of validation testing
» Capture details associated with loop testing, modeling, and optimizing
» Automatically store tuning reports and log tuning parameter changes
Simplifying Optimization:
The NSS Modeling Innovation

Control Station’s Loop-Pro Product Suite is comprised of award-winning, industrial grade process modeling and PID controller tuning software tools. Control Station is proud to have its products private-labeled or referenced by industry-leading OEMs such as Rockwell Automation, Yokogawa Corporation of America, and NovaTech Process Solutions. Each of its products is powered by the NSS Modeling Innovation and equips practitioners to tackle the complexities of highly dynamic industrial control loops —what you know as the ‘real world’.

If you experience difficulty modeling and tuning oscillatory, noisy and long Dead-Time PID control loops, contact Control Station and learn how Loop-Pro and the NSS Modeling Innovation can help you tackle your industrial strength challenges.