the Control Station guru

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Spring 2004

SHORT COURSE FOR INDUSTRY

Practical Process Control

For Engineers, Techs & Scientists
May 4 & 5, 2004

The course is intended for a mixed audience including those who have had some training in the past and seek a refresher course, and those who have not had much formal training but desire to learn more. There is little math presented because we focus on how to use methods rather than how to derive them.

We begin with a review of the fundamentals of modern PID control. We then explore proven controller design methods and tuning techniques popular in industrial practice.

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- Fundamental Dynamic Process Behavior
- Process Data Collection and Analysis
- Tuning PI, PID and PID w/ Filter Controllers
- Nonlinear Behavior and Adaptive Control
- Tuning Controllers for Industrial Applications

Day 2:
- Cascade Control Design and Tuning
- Feed Forward and Decoupling Control
- Smith Predictor for Dead Time Problems
- Control of Non-Self Regulating Processes

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Ask the Guru About Process Disturbances

***Q*:** Hey Guru, what can I do to minimize the impact of disturbances in my plant?

A. Two popular architectures for improved rejection of process disturbances are cascade control and feed forward with feedback trim. Both architectures trade off the addition of instrumentation and engineering time in return for a controller better able to reject the impact of disturbances on the measured process variable. Neither architecture benefits nor detracts from set point tracking performance.

When a traditional feedback controller works to reject a disturbance, corrective action begins only after the measured process variable has been forced away from set point. Damage to stable operation is in progress before a traditional feedback controller even begins to respond.

Consider that many disturbances originate in some other part of the plant. A measurable series of events occur that cause that "distant" event to ultimately impact your process. From this view, the traditional feedback controller simply starts too late to be effective in reducing or negating the impact of a disturbance.

A **feed forward** controller gains advantage by using a sensor to directly measure the disturbance *before* it reaches the process. As shown in Fig. 1, a feed forward element receives the disturbance measurement signal and uses it to compute and schedule preemptive control actions that will counter the impact of the disturbance just as it reaches the measured process variable.

A feed forward implementation requires the purchase and installation of a sensor and the construction of a feed forward model element. This element is comprised of a disturbance model and a process model. Both models are linear in form. The computation performed by the feed forward element may be thought of as a two step procedure:

- The *disturbance* model receives disturbance measurement, $d(t)$, and predicts an "impact profile," or when and by how much the measured process variable, $y(t)$, will be impacted.
- Given this predicted sequence of disruption to $y(t)$, the *process* model then back calculates a series of control actions, $u_{\text{feedforward}}(t)$, that will exactly counteract the disturbance as it arrives so the measured process variable remains at set point.

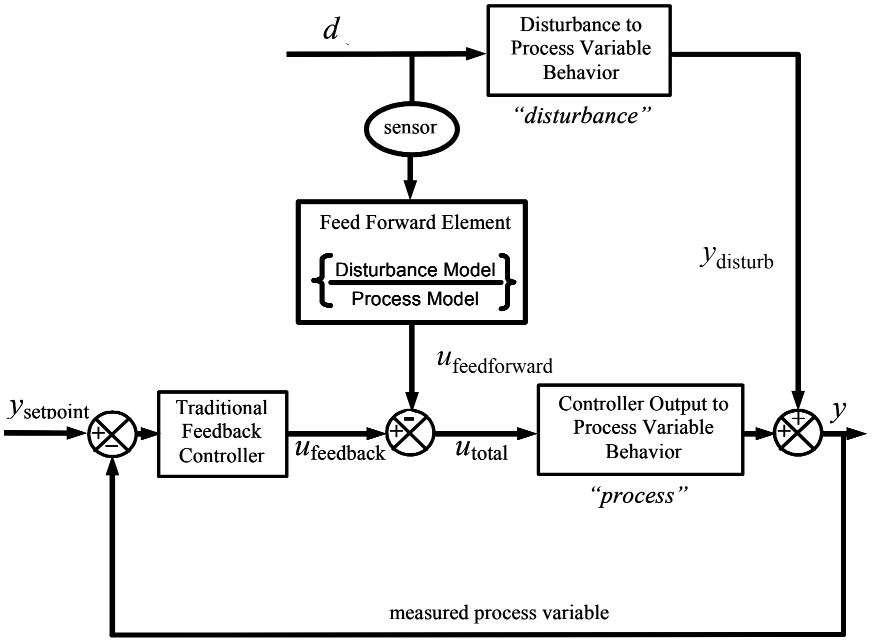

Figure 1 - feed forward controller with feedback trim

Implementation requires that these linear models be programmed into the control computer. However, linear models never exactly describe real process behavior. So although a feed forward element can dramatically reduce the impact of a disturbance, it never will succeed in providing perfect disturbance rejection.

To account for model inaccuracies, the feed forward signal is combined with traditional feedback control action, $u_{\text{feedback}}(t)$, to create a total controller output, $u_{\text{total}}(t)$. The feedback controller provides *trim*. That is, it rejects those portion of the measured disturbance that make it past the feed forward element and reach the measured process variable. The feedback controller also works to reject all other unmeasured disturbances affecting plant operation and provides set point tracking capabilities as needed.

Notice in Fig. 1 that the computed feed forward control action, $u_{\text{feedforward}}$, is subtracted from the feedback output signal to create a total controller output:

$$u_{\text{total}}(t) = u_{\text{feedback}}(t) - u_{\text{feedforward}}(t) \qquad (1)$$

This makes sense because if the disturbance model predicts that a particular disturbance will cause the measured process variable to, say, move *up* by a certain amount over a period of time, the process model must compute feed forward control actions that cause the measured process variable to move *down* in the same fashion. The negative sign enables "action opposite to prediction" to be taken.

The feed forward concept seems straightforward. In short, directly measure a nasty disturbance and use a model to instruct the controller how and when to take actions to negate its impact on the measured process variable. Developing and programming a proper dynamic model, however, can be challenging task that should not be underestimated.

Cascade control is a little more difficult to explain, yet implementation is a familiar task because the architecture is comprised of two ordinary controllers from the PID family. Like feed forward, cascade provides no benefits for set point tracking. Before you begin your design, be sure your goal is improved disturbance rejection.

In a traditional feedback loop, a controller adjusts a manipulated variable so the measured process variable remains at set point. The cascade design requires that you identify a *secondary* process variable (we call the process variable associated with original control objective the *primary* variable). Additional criteria include that:

- the secondary variable is measurable with a sensor,
- the same valve used to adjust the primary variable must also manipulate the secondary variable,
- the same disturbances of concern for the primary variable must also disrupt the secondary variable,
- the secondary variable must be *inside* the primary process variable, which means it responds before the primary variable to disturbances and valve manipulations.

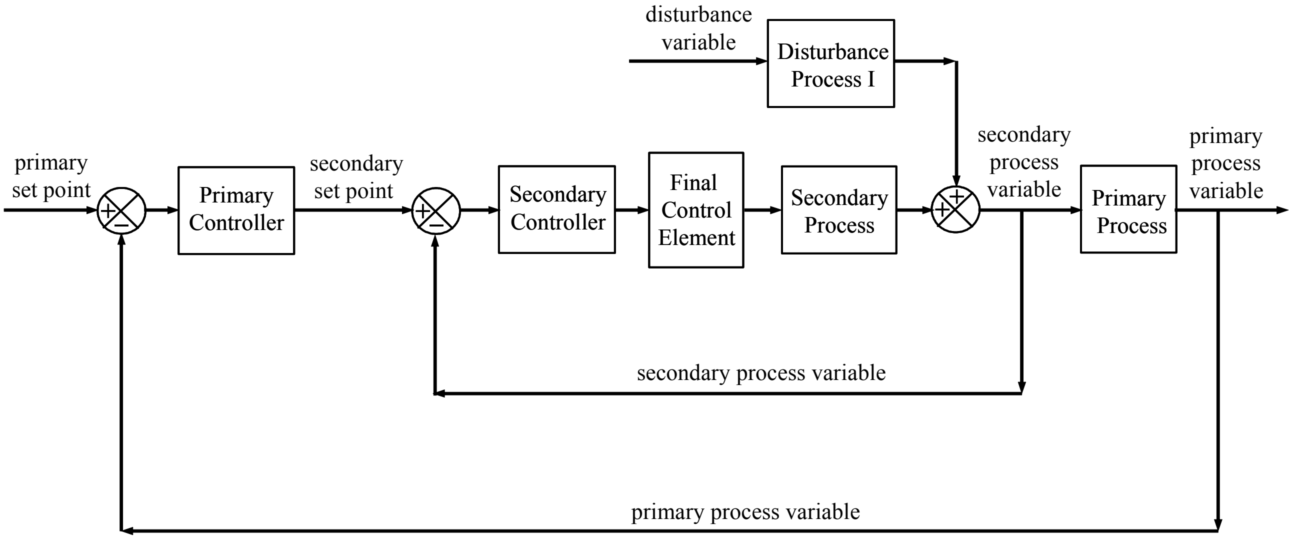

Figure 2 - cascade control architecture

With a secondary process variable identified, a cascade is constructed as shown in Fig. 2. The block diagram shows how both Disturbance I and the final control element impact the secondary variable before they affect the primary variable. Notice that the secondary loop has a traditional feedback control structure, except here it is literally nested inside the primary loop.

A cascade requires two sensors and two controllers but only one final control element because the output of the primary controller, rather than going to a valve, becomes the set point of the secondary controller. Because of the nested architecture, success in a cascade implementation requires that the settling time of the (inner) secondary loop is significantly faster than the settling time of the primary (outer) loop.

As the above discussion implies, one advantage of a control cascade is that it is not tied to a single disturbance. Rather, the same cascade can address multiple disturbances as long as each impacts the inner secondary variable well before it impacts the outer primary variable. Also, as mentioned before, implementation uses our existing skills because the architecture is comprised of two ordinary controllers from the PID family.

Cascade loop tuning proceeds as follows:

- begin with both controllers in manual mode.
- select a P-Only controller for the inner secondary loop (integral action increases settling time and offset is rarely an issue for this variable).
- tune the secondary P-Only controller focusing on set point tracking (its main job is to respond to set point commands from the primary controller).
- leave the secondary controller in automatic; it now becomes part of the primary process.
- select a PI or PID controller for the primary controller
- tune the primary controller for disturbance rejection performance
- with both controllers in automatic, tuning of the cascade is complete.

Contact Information

The Process Control Consortium is a UConn partnership with industry dedicated to research, training and technology transfer in process control.

For more information on the Consortium, our Control Station software, our training for industry, and our research, visit our website or contact:

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