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CHE532: PROCESS DYNAMICS AND CONTROL II

A TERM PAPER ON CASCADE CONTROL

DEPARTMENT OF CHEMICAL ENGINEERING AND PETROLEUM ENGINEERING

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ABSTRACT

This term paper gives a general overview on Cascade control as an enhanced single-loop control strategy.

Keywords:

Control, Cascade, Loop, Dynamics, Set point, Tune

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LIST OF ABBREVIATIONS

PID	Proportional Integral Derivative

1 INTRODUCTION

1.1 Overview

Cascade control can be generally seen as one of the specialized strategies that provides enhanced process control beyond what can be obtained with conventional single-loop PID controllers. As processing plants become more and more complex in order to increase efficiency or reduce costs, there are incentives for using such enhancements, which also fall under the general classification of advanced control (Dale E. Seborg, 1989). Some of the different strategies of enhanced single loop control continually evolving proven commercially includes;

1. Cascade control
2. Time-delay compensation
3. Inferential control
4. Selective and override control
5. Nonlinear control
6. Adaptive control

These techniques have gained increased industrial acceptance over the past 20 years, and in many cases they utilize the principles of single-loop PID feed-back controller design. These strategies can incorporate additional measurements, controlled variables, or manipulated variables, and they can also incorporate alternative block diagram structures (Dale E. Seborg, 1989).

1.2 Cascade Control

A disadvantage of conventional feedback control is that corrective action for disturbances does not begin until after the controlled variable deviates from the set point. Feedforward control offers large improvements over feedback control for processes that have large time constants or time delays. However, feedforward control requires that the disturbances be measured explicitly, and that a model be available to calculate the controller output.

An alternative approach, and one that can significantly improve the dynamic response to disturbances, employs a secondary measurement point and a secondary feedback controller. The secondary measurement point is located so that it recognizes the upset condition sooner than the controlled variable, but the disturbance is not necessarily measured. This approach is referred to as **Cascade Control** (Dale E. Seborg, 1989)**.**

In Single-loop control, the controller's set point is set by an operator, and its output drives a final control element. For example; a level controller driving a control valve to keep the level at its set point.

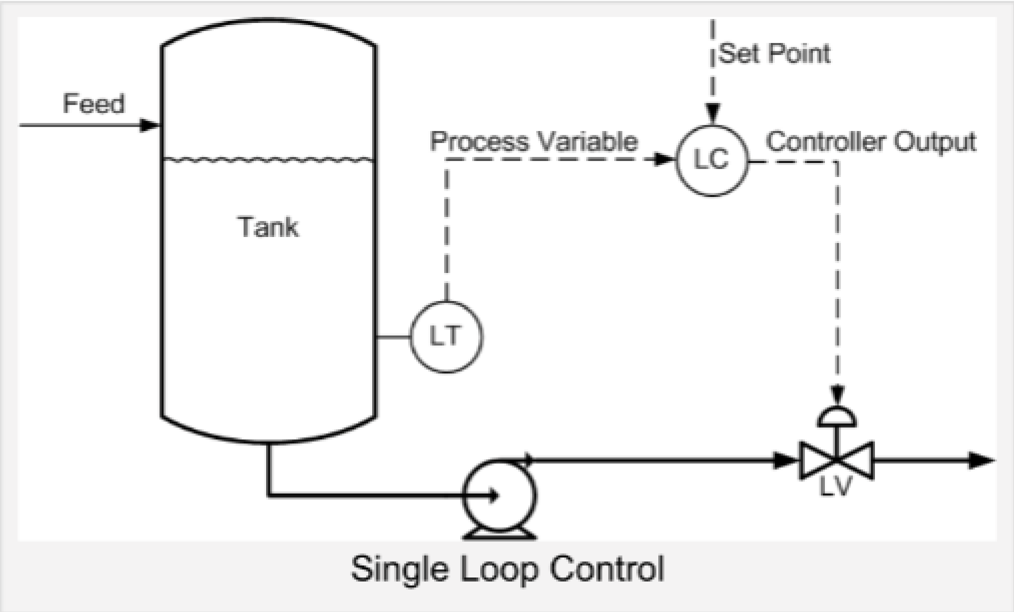

Figure 1-1: Single Loop Control

In a cascade control arrangement, there are two (or more) controllers of which one controller's output drives the set point of another controller. For example; a level controller driving the set point of a flow controller to keep the level at its set point. The flow controller in turn drives the control valve to match the flow with the set point the level controller is requesting (Smults, 2010)

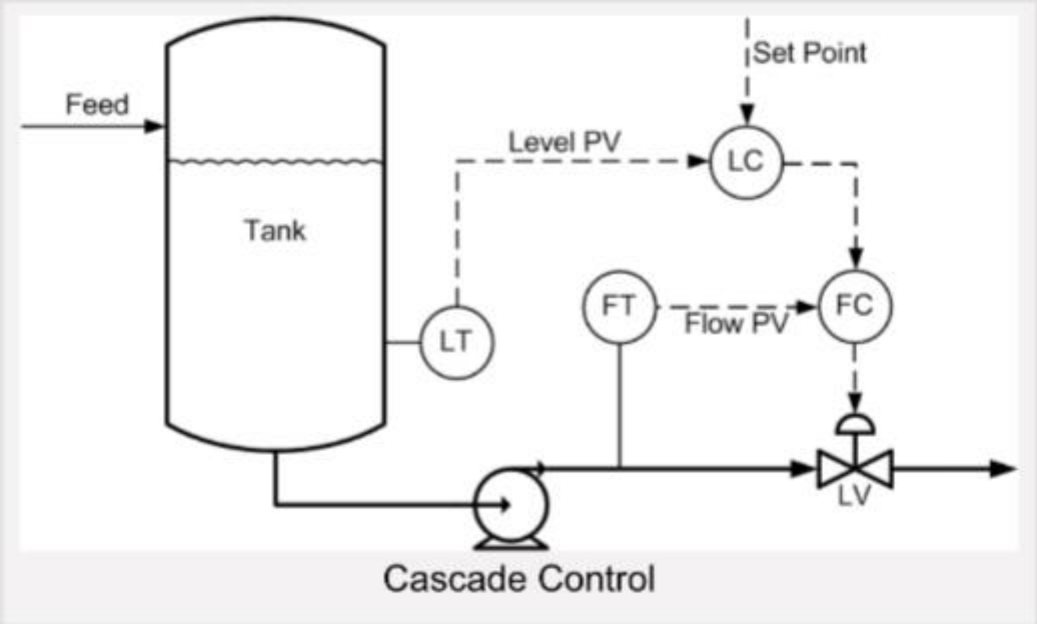

Figure 1-2: Cascade Control

The controller driving the set point (the level controller in the example above) is called the Primary, outer or master controller. The controller receiving the set point (flow controller in the example) is called the secondary, inner or slave controller (Smults, 2010)

1.2.1 Advantages of Cascade Control

There are several advantages of cascade control, and most of them includes isolating a slow control loop from non-linearity in the final control element. In the example above, the relatively slow level control loop is isolated from any control valve problems by having the fast flow control loop deal with these problems (Smults, 2010)

1.2.2 Disadvantages of Cascade Control

1. Additional measurement required
2. Additional control required. So, controller tuning of secondary controller is required

These disadvantages have to be weighed up against the benefits of the expected improvement in control to decide if cascade control should be implemented (Smults, 2010)

1.2.3 When to use cascade control

Cascade control is usually used in the case of a process with relatively small dynamics (like level, temperature, composition, humidity) and a liquid or gas flow, or some other relatively-fast process has to be manipulated to control the slow process. For example: changing cooling water flow rate to control condenser pressure (vacuum), or changing steam flowrate to control heat exchanger outlet temperature. In both cases, flow control loop should be used as inner loops in cascade arrangements.

1.2.4 When not to use cascade control

Cascade control is beneficial only if the dynamics of the inner loop are fast compared to those of the outer loop. Cascade control should generally not be used if the inner loop is not at least three times faster than the outer loop, because the improved performance may not justify the added complexity.

In addition to the diminished benefits of cascade control when the inner loop is not significantly faster than the outer loop, there is also a risk of interaction between the two loops that could result in instability-especially if the inner loop is tuned very aggressively.

1.2.5 How cascade control should be tuned

A cascade arrangement should be tuned starting with the innermost loop. Once that one is tuned, it is placed in cascade control, or external set point mode and then, the loop driving its set point is tuned. Methods such as Ziegler-Nichols and Cohen-Coon rules shouldn’t be used to tune control loops in a cascade structure because it can cause instability if the process dynamics of the inner and outer loops are similar.

2 Theoretical Background

2.1 Design Considerations for Cascade Control

Below is a standard block diagram for a cascade control system

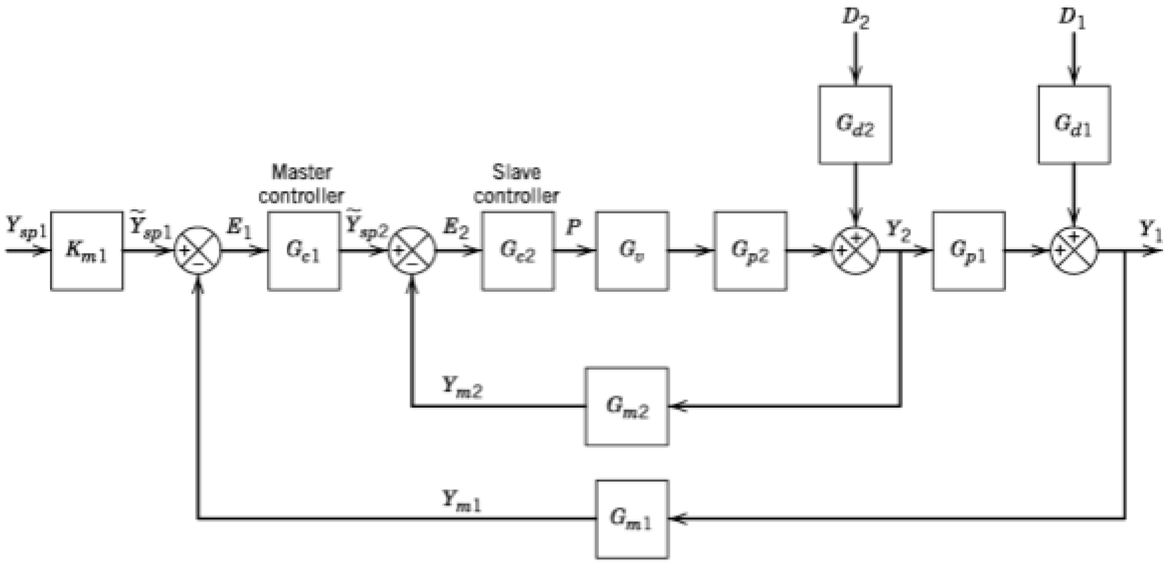

Figure 2-1: Block diagram of the cascade control system

Where disturbance variables (D1 and D2) and two disturbance transfer functions (Gd1 and Gd2) are shown in Figure 2-1above

Cascade control can improve the response to a set point change by using an intermediate measurement point and two feedback controllers. However, its performance in the presence of disturbances is usually the principal concern (Dale E. Seborg, 1989). In Figure 2-2, disturbances in D2 are compensated by feedback in the inner loop; the corresponding closed-loop transfer function (assuming Yspl = D1 = 0) is obtained by block diagram algebra

$$Y1 = Gp1Yz \quad \textbf{(2-1)}$$

$$Y2 = Gd2D2 + Gp2GvGc2E2 \quad \textbf{(2-2)}$$

$$E2 = Ysp2 - Y\,m2 = Gc1E1 - Gm2Y2 \quad \textbf{(2-3)}$$

$$E1 = -Gm1Y1 \quad \textbf{(2-4)}$$

Eliminating all variables except Y1 and D2 gives

$$\frac{Y1}{D2}=\frac{Gp1Gd2}{1+Gc2GvGp2Gm2+Gc1Gc2GvGp2Gp1Gm1} \quad \textbf{(2-5)}$$

By similar analysis, the set-point transfer functions for the outer and inner loops are

$$\frac{Y1}{Ysp1}=\frac{Gc1Gc2GvGp1Gp2Km1}{1+Gc2GvGp2Gm2+Gc1Gc2GvGp2Gp1Gm1} \quad \textbf{(2-6)}$$

$$\frac{Y2}{Ysp2}=\frac{Gc2GvGp2}{1+Gc2GvGp2Gm2} \quad \textbf{(2-7)}$$

For disturbances in D1, the closed-loop transfer function is

$$\frac{Y1}{D2}=\frac{Gd1(1+Gc2GvGp2Gm2)}{1+Gc2GvGp2Gm2+Gc1Gc2GvGp2Gp1Gm1} \quad \textbf{(2-8)}$$

Several observations can be made about the above equations. First, the cascade control system has the characteristic equation

$$1 + Gc2GvGp2Gm2 + Gc1Gc2GvGp2Gp1Gm1 = 0 \quad \textbf{(2-9)}$$

If the inner loop were removed (Gc2 = 1, Gm2 = 0), the characteristic equation would be the same as that for conventional feedback control,

$$1 + Gc1GvGp2Gp1Gm1 \quad \textbf{(2-10)}$$

When the slave loop responds faster than the master loop, the cascade control system will have improved stability characteristics and thus should allow larger values of Kc1 to be used in the primary control loop. Cascade control also makes the closed-loop process less sensitive to errors in the process model used to design the controller (Dale E. Seborg, 1989).

References

1. Dale E. Seborg, T. F. (1989). *Process Dynamics and Control.* Santa Barbara and Austin.

2. Smults, J. (2010, March 15). Retrieved from blog.opticontrols.com.