

Abu Dhabi National Oil Co.

ADNOC Technical Institute

أدنوك
ADNOC

شركة بنزول أبوظبي الوطنية



INSTRUMENTATION

ADVANCED PROCESS CONTROL FUNDAMENTALS

UNIT 7

CASCADE CONTROL LOOP TUNING

UNITS IN THIS COURSE

UNIT 1	INTRODUCTION TO PROCESS CONTROL
UNIT 2	MODES OF CONTROL
UNIT 3	PROPORTIONAL CONTROL
UNIT 4	PROPORTIONAL PLUS INTEGRAL CONTROL
UNIT 5	PROPORTIONAL PLUS INTEGRAL PLUS DERIVATIVE CONTROL
UNIT 6	CONTROL LOOPS TUNING
UNIT 7	CASCADE CONTROL LOOP TUNING
UNIT 8	RATIO CONTROL LOOP TUNING
UNIT 9	CONTROL LOOP TROUBLESHOOTING

TABLE OF CONTENTS

Paragraph	Page
7.0 TERMINAL OBJECTIVE	4
7.1 ENABLING OBJECTIVES	4
7.2 PART I: DESCRIBE OPERATING PRINCIPLES AND APPLICATIONS OF CASCADE CONTROL	5
7.3 PART II: DESCRIBE THE FUNCTION OF CASCADE LOOP COMPONENTS	13
7.4 PART III: DESCRIBE THE PROCEDURES FOR TUNING A CASCADE CONTROL LOOP	14
7.5 TROUBLE SHOOTING	19
7.6 TASK STEPS	20

7.0 TERMINAL OBJECTIVE:

Given a process simulator with an operating cascade control loop that needs tuning, Ziegler-Nichols formulas, and the necessary tools, the trainee will be able to tune the loop for stable loop performance. After a step set point change of 5% is made in the automatic mode, the tuned control loop must produce a one-quarter decay ratio curve and control at the set point within $\pm 2\%$ of the chart scale.

7.1 ENABLING OBJECTIVES:

- 7.1.1 Unaided, the trainee will be able to correctly describe operating principles and applications of cascade control.
- 7.1.2 Given a P&ID and an ILD of a cascade control loop, the trainee will be able to correctly describe the functions of loop components.
- 7.1.3 Unaided, the trainee will be able to describe the procedure for tuning a cascade control loop, without error.

MATERIALS:

P&ID A 287 NA-932451 Sheets 9 and 10

ILD J 287 NB-932714 Sheets 102 and 206

7.2 PART I: DESCRIBE OPERATING PRINCIPLES AND APPLICATIONS OF CASCADE CONTROL.

What is a cascade control loop? What makes it different from a simple control loop? Why are cascade control loop used? This section of the Information Sheets will answer these questions for you.

To make cascade control loops easy to understand, we can divide the cascade loop into two parts: **a Primary Loop** and **a Secondary Loop**. But keep in mind that the two loops are parts of one system where one variable is being controlled by the other. The primary and secondary loops perform different functions. Think of it this way:

- The Primary Loop determines what the set point of the Secondary Loop will be.
- The Secondary Loop operates the loop control valve.

So the primary loop controls the set point. The secondary loop controls the valve position. With this concept in mind let us see how a cascade loop works.

Figure 7.01 is a simple heat exchanger process.

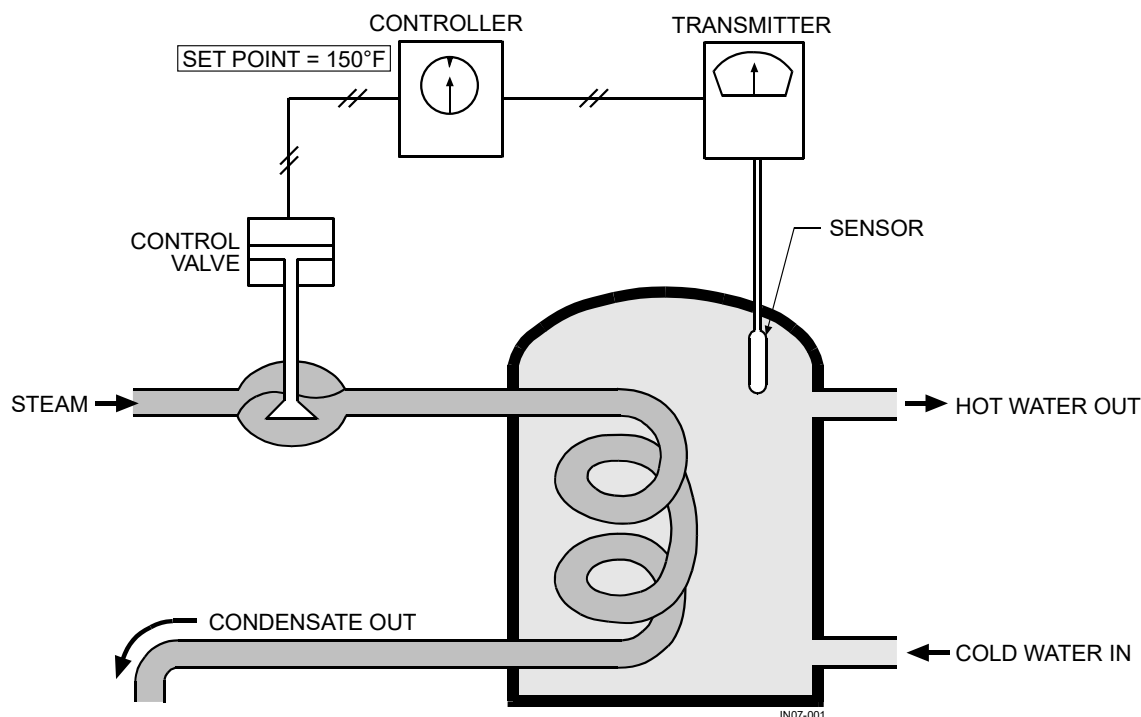


Figure 7.01 – Heat Exchanger

You should recall that a heat exchanger was used to explain the principle of derivative control. You saw how derivative action can be used to overcome the slow response to changes in the temperature control system.

The process in Figure 7.01 is a heat exchange process. Steam flows through the tube side of the exchanger. The steam gives up heat to raise the temperature of the cold water.

Let's say that steam temperature is 450°F coming into the heating coil. The cold water temperature is 80°F. We want hot water to come out of the vessel at 105°F. In the heat exchange process, the 350°F steam must give up enough heat to raise the water temperature to the 150°F set point. In the process, the steam temperature falls to 250°F. As long as the inlet steam

temperature and flow stay constant, and the flow of water in and out of the vessel stays the same, the process will be stable.

But what happens if there is a load change? For example, imagine that the flow of water out of the vessel decreases, the water will stay in the vessel longer. More heat will be exchanged, and the water temperature will rise above the 150°F set point. As soon as the controller detects the deviation from set point of the water temperature, it will start to close the control valve. This decreases the amount of steam entering the system.

The control loop can respond to large changes in demand to bring the water temperature back to the set point. But there is a long time lag in the control system. To see the effect of this time lag, imagine that the inlet steam temperature rises from 350°F to 370°F. The controller has no way of detecting this change until the extra heat raised the water temperature above the set point. It will take the controller a long time to remove the extra heat from the system. Our control system is too slow – we need a way to detect and respond to changes more quickly.

Figure 7.02 shows a different way to control the heat exchanger process. The sensing element has now been placed in the steam condensate line. The controller set point is 250°F.

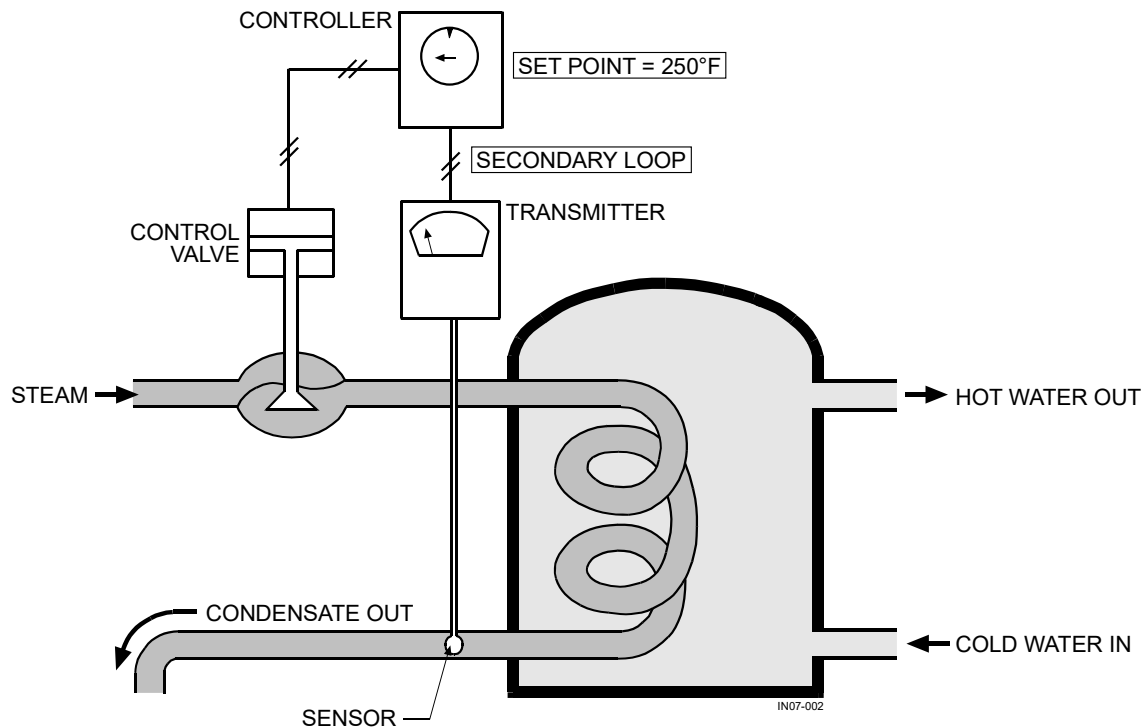


Figure 7.02 – Heater Secondary Loop

The sensor detects the temperature of the steam or condensate when it leaves the heating coil. The controller can determine how much heat exchanging is taking place in the vessel. The controller will compare the temperature of the outlet steam/condensate against its set point.

This control loop will respond to changes in the heat exchanger system very quickly. If the temperature of the incoming steam increases, the controller will immediately detect the higher temperature of the outlet steam condensate. It will respond by closing the control valve, reducing the flow of steam, and keeping the temperature at the set point. But there is a problem. Without help, the controller will not respond in the right proportion to a large

demand change. For example, imagine that operations reduce the flow of hot water through the system by 50%. The water will now remain in the exchanger twice as long. The water will continue to absorb most of the heat from the steam entering the system. Since most of the heat is transferred, there will only be a small increase in the steam condensate temperature sensed by the transmitter. But, the temperature of the water will be increasing well beyond limits. This is a serious problem with our control loop – the controller may not correctly interpret the size, or magnitude of a process upset.

Our first loop responded effectively to the magnitude of process changes, but responded too slowly. Our second loop responded to changes in steam temperature more quickly, but could not accurately detect the size of the load change. To best control the process, we need to combine the advantages of both loops. This is what cascade control does.

Figure 7.03 shows the two loops combined in a single cascade control loop.

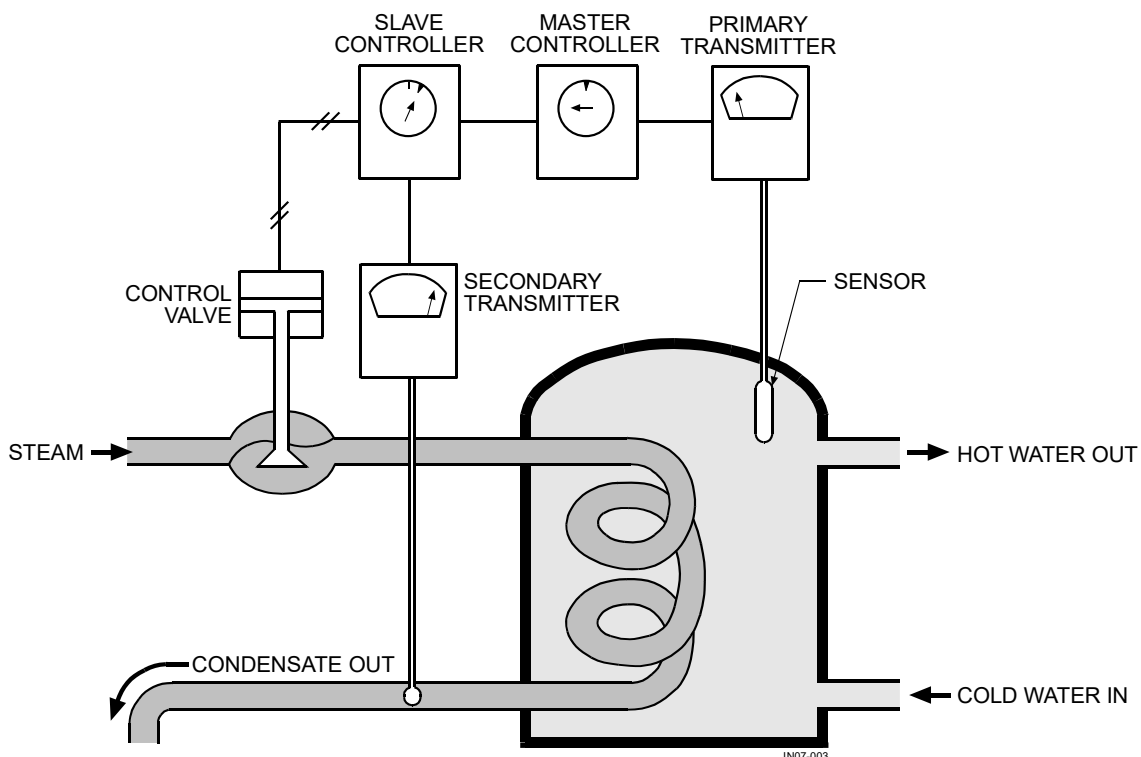


Figure 7.03 Heat Exchanger Loop

Can you see how a system like this will solve the time lag problem in the control system while responding to large upsets effectively?

The primary loop sensor measures the temperature of the outlet water. The primary (master) controller compares this measurement to a set point and its output established the set point for the secondary (slave) controller.

The sensor in the secondary loop measures the temperature of the outlet steam condensate. The slave controller compares the steam temperature with the set point from the master controller. When the steam condensate, temperature drops below the set point, it opens the valve. If the temperature rises above the set point, it closes the valve in.

In the secondary loop, the sensor is detecting the temperature in a much smaller volume. The temperature changes in the heater coil occur much faster than in the heater vessel. Since the temperature changes are detected faster, control valve adjustments are made sooner, so they have a greater effect on the process.

If there are no large process upsets, the secondary or slave controller will do most of the work in the cascade loop. The secondary loop will detect the correct most small process upsets before the primary, or master controller can sense a change in the system. But, whenever a large change occurs, the master controller will step in. It will dictate the size of the control valve response by changing the set point of the slave controller.

All cascade loops operate on the same principle as our heat exchanger control system. A cascade system consists of a primary (master) and secondary (slave) controller. The master controller controls the primary process variable, which must be kept at a constant value. The slave controller controls a second variable which can cause fluctuations in the primary

variable. The master controller positions the set point of the slave controller. The slave controller positions the control valve, adjusting the secondary variable as necessary to keep the primary variable at set point.

What makes a cascade loop different from a simple process loop?

A cascade loop will have **two sensing elements, two transmitters, two controllers, and one valve**. If there is a recorder, it will usually be in the secondary loop. The secondary loop will also have a transducer to operate the valve.

Why are cascade loops used?

To provide better control of a process by reducing time lag in a system to a minimum. Better process control produces better products.

ADNOC uses cascade control where a process may depend on the performance of an entirely different variable than the process variable. You saw an example of that in Module 2.1. Figure 7.04 shows a cascade control application where a master level controller established the set point for a slave controller to control flow rate. Using level to control flow is a common application of cascade control in ADNOC.

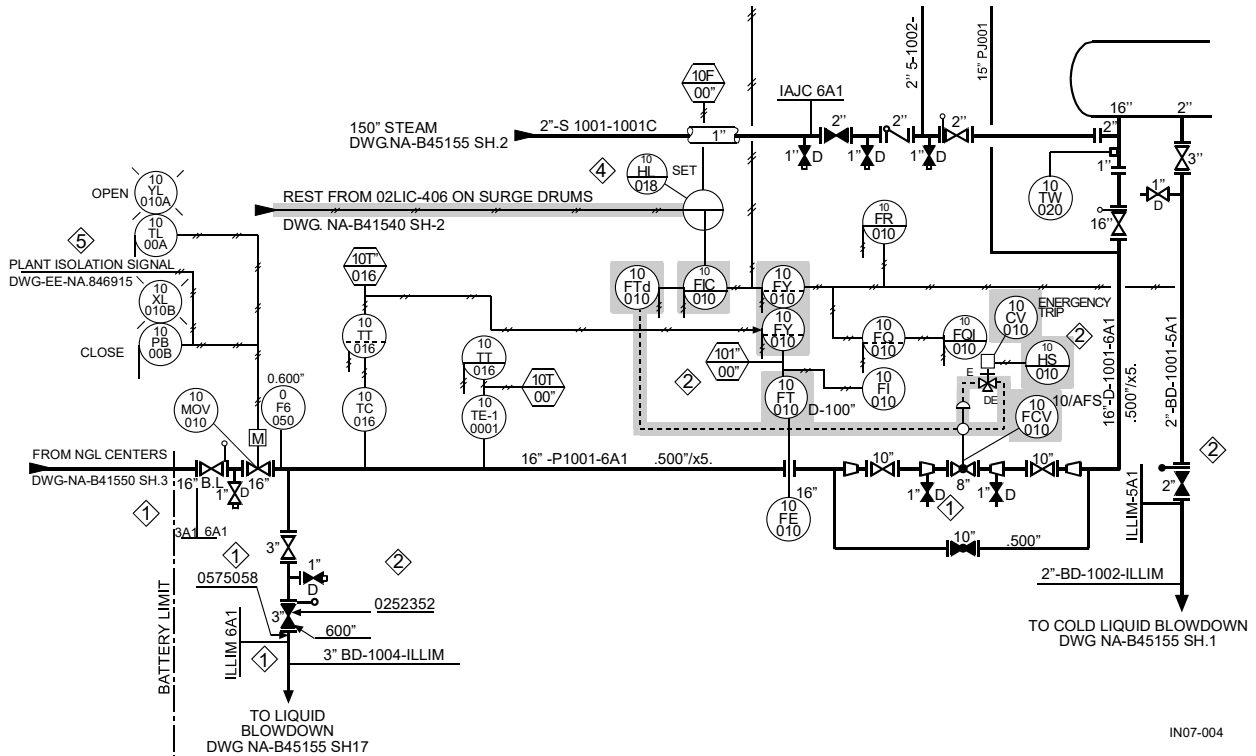


Figure 7.04 – Pre-heater Process Flow Loop

The P&ID shows the flow loop that controls the flow of NGL into a pre-heater process. The flow controller, FIC-010, receives its set point from a level controller, LIC-406. The pre-heating process is based upon how much NGL flows into the pre-heater. The flow rate is based on the level in the surge drums in another part of the plant. As the level in the surge drums changes, the set point for the flow controller changes.

7.3 PART II: DESCRIBE THE FUNCTION OF CASCADE LOOP COMPONENTS:

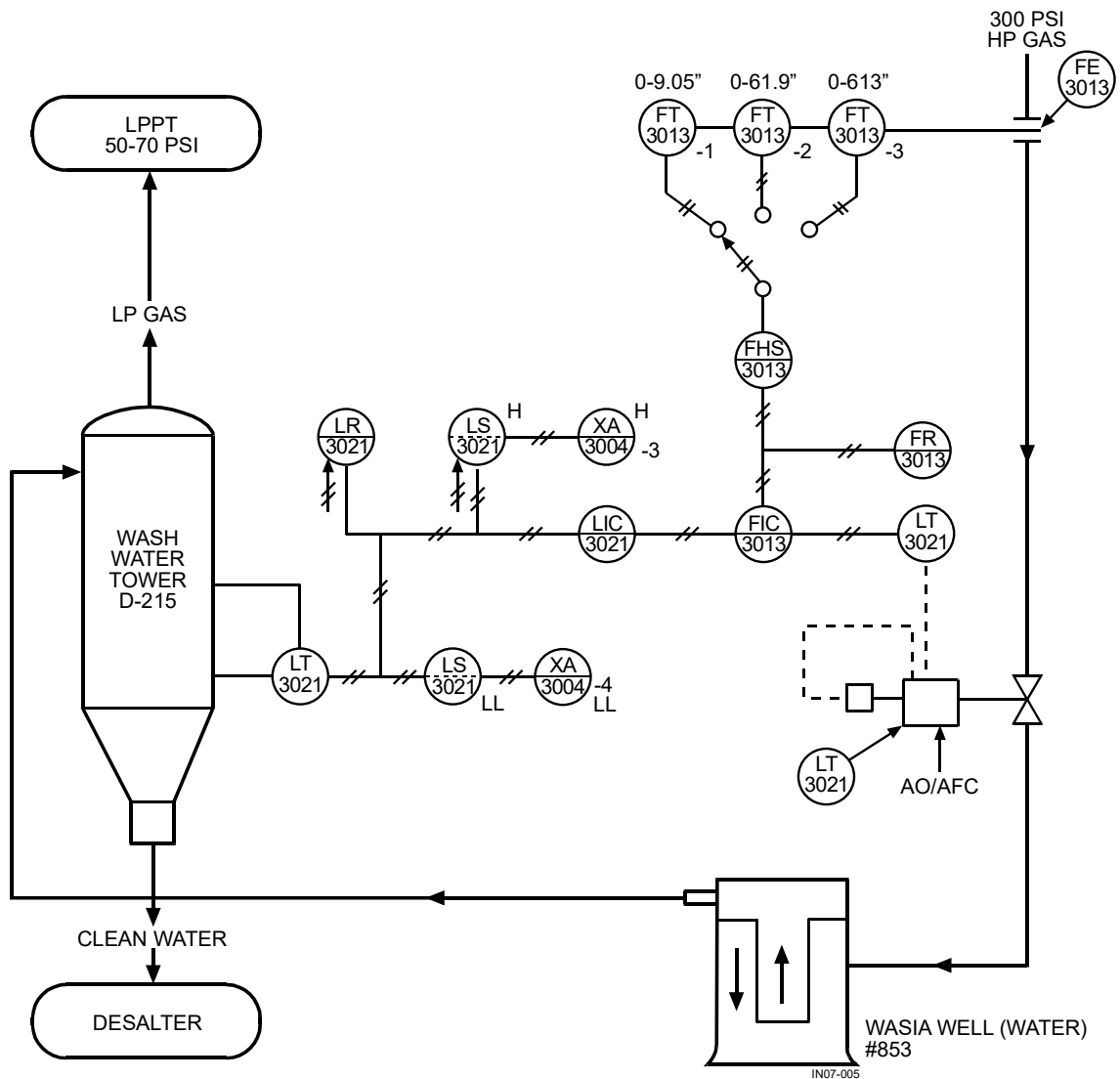


Figure 7.05 – A Level/Flow Cascade Control Loop

7.4 PART III: DESCRIBE THE PROCEDURE FOR TUNING A CASCADE CONTROL LOOP:

We have already tuned Foxboro and Honeywell controllers. The controllers were parts of simple, single process loops. Tuning a cascade control loop requires a special tuning procedure. This is because the two loops in a cascade system depend upon each other. The secondary loop can be isolated from the primary loop, but the primary loop cannot be isolated from the secondary loop.

Because the secondary loop can be isolated, it is tuned first. When the secondary loop is isolated, it becomes an ordinary loop. The tuning procedure is exactly the same as before. You will use Ziegler-Nichols formulas and will be looking for $\frac{1}{4}$ decay reaction curves. A Task Sheet will furnish the formulas you will need for the module task and the Performance Test.

Before you begin the task, you should review tuning procedures we learned before. Pay particular attention to the information about reaction curves and how analyzing the curves can tell you what adjustments you need to make to achieve the $\frac{1}{4}$ decay reaction curve. You will need that knowledge when you tune the primary loop. You will have to use the trial and error method for the primary loop.

You will start the module task with both loops set in the cascade mode. For Foxboro instruments, the slave controller will be set for REMOTE (R). The master controller will be set to LOCAL (L). For Honeywell instruments, the slave controller will be set to "C" (CASCADE) and the master controller will be set to "A" (AUTO).

The first thing you should do is to observe the chart recorder to see just what the loop is doing. Then switch both loop controllers to the MANUAL, or LOCAL, setting.

When you have switched the controller to manual, the slave controller is isolated and can be tuned. Be sure you know which controller is the slave. Be sure you know which pen on the recorder is recording the secondary loop if more than one pen is operating.

Use the procedure you learned before to tune the secondary loop.

When you have achieved a $\frac{1}{4}$ decay reaction curve with the slave controller, you are ready to tune the primary loop.

You may be wondering why the master controller needs to be tuned. If the secondary loop is tuned for a good reaction curve, (which means good process control) and the entire master controller is going to do is to provide a set point, why does the master controller need tuning?

There is a simple answer to that question – to prevent over-reaction by the secondary loop when the master controller changes the set point. The master controller must be tuned to give a CONTROLLED output signal to the slave controller. Otherwise, the slave controller will be continuously chasing a moving set point.

When the secondary loop is accurately tuned, switch the slave controller to "R" for Foxboro or "C" for Honeywell. The slave controller is now ready to respond to master controller set point changes.

The master controller is in MANUAL. Leave it in manual initially. You know that your first tuning step is to stabilize the process at the set point. The

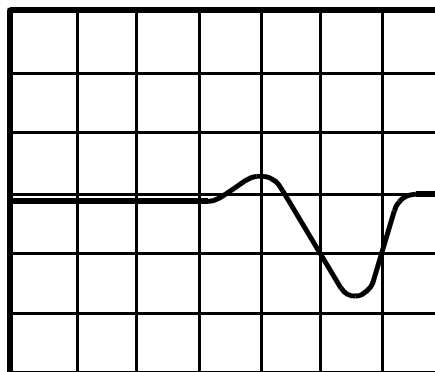
process variable the master controller is monitoring is not the same variable the slave controller is monitoring.

The tuning procedure for the master controller is almost the same as for the slave controller. The differences are that you will not use Ziegler-Nichols formulas and you are not trying to achieve an Ultimate Proportional Band or Ultimate Gain reaction curve. You will use the trial and error method to go right to the $\frac{1}{4}$ decay reaction curve. The recorder in the secondary loop will be recording the reaction curve. Task Aid steps will guide you through the cascade loop tuning steps.

Remember, you achieved a good reaction curve on the slave controller earlier. Do **NOT** touch the settings on the slave controller while you tune the master controller or you will have to start all over.

Also remember that when you tune the master controller for proportional band or gain, you may get some offset with a good $\frac{1}{4}$ decay curve. You will eliminate the offset when you tune the master controller for integral. You will not tune the controllers for derivative.

Since you will not have a formula to get the PB or Gain and Integral settings close to the proper $\frac{1}{4}$ decay curve, you will have to analyze the recorder reaction curves. The illustrations below are the reaction curves for a proportional-only controller.



PB too high.

Figure 7.6 A

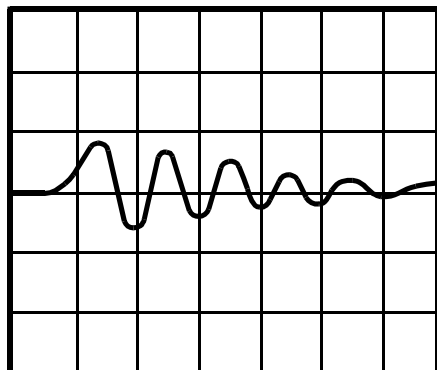


Figure 7.6 B

PB too low.



Figure 7.6 C

PB Correct. Some offset may occur.

The illustrations below are reaction curves for a proportional plus integral controller.

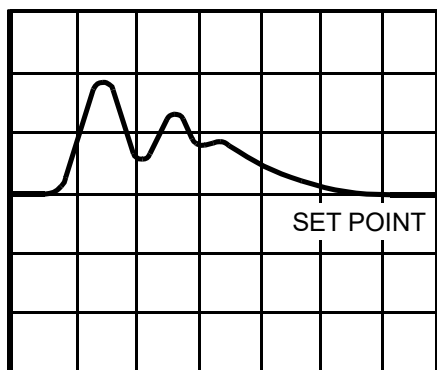


Figure 7.6D

Too little INTEGRAL action

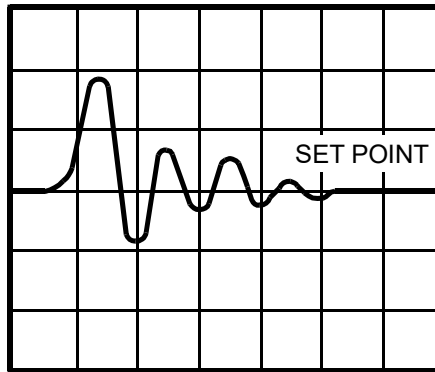


Figure 7.6 E

Too much INTEGRAL action

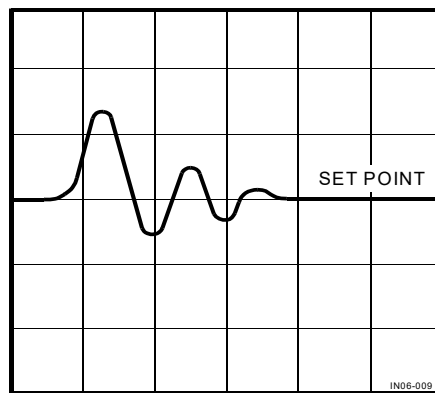


Figure 7.6F

Correct INTEGRAL action

When the reaction curve in Figure 7.6F has been achieved, the primary loop is tuned. Switch the master controller to "L" Foxboro or "A" for Honeywell. A correctly tuned cascade loop is now operating.

7.5 TROUBLESHOOTING AND REPAIRING ADVANCED CONTROL LOOPS:

Given a process simulator with an operating cascade control loop that needs tuning, Ziegler-Nichols formulas, and the necessary tools the trainee will be able to tune the loop for stable loop performance. After a step set point change of 5% is made in the automatic mode, the tuned control loop must produce a one-quarter-decay ratio curve and control at the set point within $\pm 2\%$ of the chart scale.

TOOLS AND EQUIPMENT:

Small Flat Blade Screwdriver

MATERIALS:

P&ID for process simulator

ILDs for process simulator

SPECIAL INSTRUCTIONS:

Practice this task with the Foxboro controllers used in the Lab-Volt system. Use the same procedures to tune the Foxboro Controllers for the Performance Test.

7.6 TASK STEPS:

1. Set the master and slave controllers in MANUAL mode.
2. Set both controller set points at 50% of indicator scale.

TUNE THE SECONDARY LOOP CONTROLLER

3. Stabilize the process measurement at the set point.
4. Set the integral dial for minimum action (fully clockwise).
5. Set the derivative dial to OFF.
6. Set proportional band to its maximum setting.
7. Switch the controller to the AUTOMATIC mode.
8. Move the set point 2% to cause a process disturbance.
9. Return the set point to 50% as soon as the measurement pointer begins to move.
10. Check the recorder for cycling. Look for an Ultimate PB curve.
11. Reduce the PB setting by half.
12. Repeat steps 8 through 11 until Ultimate PB is achieved.
13. Determine the Ultimate Period.
14. Calculate the PB and integral settings for a $\frac{1}{4}$ decay reaction curve. (See Task Sheet 1 for formulas).
15. Switch the controller to MANUAL.
16. Set PB and integral for values calculated in Step 14.
17. Stabilize the measurement pointer at the set point.
18. Switch the controller to AUTOMATIC.
19. Move the set point 2% to cause a process disturbance.
20. Check the recorder for a $\frac{1}{4}$ decay reaction curve.

21. Make small adjustments in PB and/or integral settings to achieve the ideal $\frac{1}{4}$ decay reaction curve.

Note: *Repeat this entire procedure if the reaction curve is not satisfactory. Do not start the master controller tuning procedure until the slave controller is correctly tuned.*

22. Switch the slave controller to REMOVE mode.

Note: *For a Honeywell Controller, switch to C for Cascade.*

TUNE THE MASTER CONTROLLER

23. Check that the controller is set in MANUAL mode.
24. Stabilize the process measurement at the set point. Observe the primary controller indicator scale and the secondary loop recorder.
25. Set the integral dial for minimum action (fully clockwise).
26. Set the derivative dial to OFF.
27. Set the proportional band to a high value but less than a maximum.

Example: If the PB scale maximum setting is 500, set PB to 400.

28. Switch the controller to AUTOMATIC mode.
29. Cause a process disturbance. Move the master controller set point 2%.
30. Return the set point to 50% as soon as the measurement pointer moves.
31. Observe the reaction curve on the secondary loop recorder. Look for a $\frac{1}{4}$ decay reaction curve.

Note: *Some offset is okay.*

32. Reduce the PB setting by half.

33. Repeat Steps 29 through 32 until a $\frac{1}{4}$ decay reaction curve is produced on the secondary loop recorder.
34. Switch the controller to manual mode.
35. Stabilize the process measurement at the set point.
36. Set the integral dial to its fastest action (counter-clockwise).
37. Switch the controller to automatic mode.
38. Cause a process disturbance.
39. Return the set point to 50% as soon as the process reacts.
40. Observe the reaction curve on the secondary loop recorder. Look for a $\frac{1}{4}$ decay reaction curve with no offset.
41. Reduce the integral setting by half.
42. Repeat Steps 38 through 41 until a $1/$ decay reaction curve with no offset is produced on the secondary loop recorder.

Note: Repeat the master controller tuning procedure if the reaction curve is not satisfactory. Do not change the slave controller settings.

43. Switch the master controller to AUTOMATIC (L) mode.

Note: For a Honeywell Controller, switch the master controller to "A" for AUTOMATIC MODE.