Date: ________________ Name: ___________________________________

DEMONSTRATION EXERCISE 19
FORWARD DECOUPLING CONTROL

OBJECTIVE: To acquaint the student with the need for decoupling control for interacting processes, and to familiar the student with implementation of one form of decoupling and of the advantage of decoupling interacting control loops.

PREREQUISITE: Completion of Exercise

9	PID Tuning from Open Loop Tests
11	Improving "As Found" Tuning

BACKGROUND: In many processes, control loops interact with each other. Control action of one final control element (valve) affects not only its own process variable, but also one or more process variables of other control loops. Control action by the other loops, in turn, affects their own process variables, also the process variable of the original loop.

Examples of interacting loops:

> Distillation control. Perhaps the overhead product composition is being controlled by either reflux flow or product flow rate, while the bottom composition is being controlled by reboiler heat. A change in reflux or product flow rate will have some effect on bottom composition as well as top composition. Likewise, a change in reboiler heat rate will affect the top composition as well as the bottom composition.
>
> HVAC. Suppose temperature and humidity are both being controlled, for instance, for a clean room application or environmental test facility. The humidity will probably be controlled by cooling to remove moisture, and the temperature by reheating. However, a change in either the cooling or heating input will affect both the temperature and humidity.

One approach to coping with interacting loops is to provide "decoupling." Additional compensation elements are inserted between the primary controllers' outputs and the final control elements. Each final control element, then, is affected by a combination of all the controller outputs. The intent is to make the loops appear as if they were decoupled; that is, each controller output affects only its own process variable.

Two forms of decoupling are called "forward" and "inverted". This exercise illustrates forward decoupling; a subsequent demonstration exercise illustrates inverted decoupling.

This laboratory exercise is written around a generic 2-input, 2-output process. A process and control configuration diagram is shown in Figure 1.

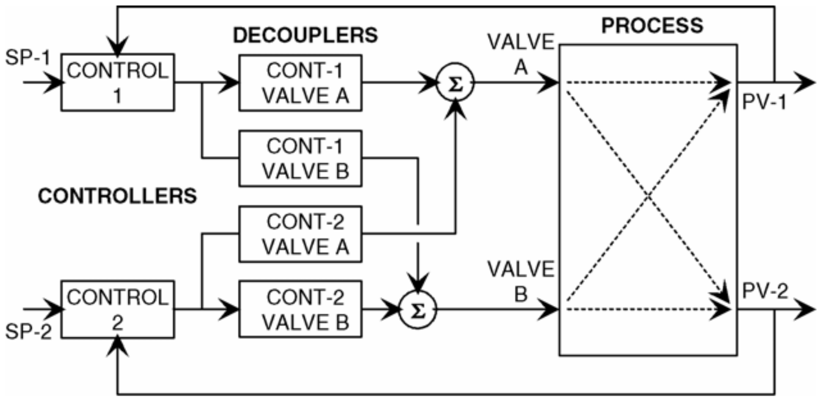

Figure 1
INTERACTING PROCESS WITHFORWARD DECOUPLERS

In real-life applications, the combined signals from a primary controller and a decoupling element would probably set the set point of a lower level flow controller, for instance a reflux flow controller or steam-to-reboiler flow controller. In **PC-ControLAB**, screen size limitation prevents having two primary controllers and two secondary controllers, along with a useable width strip chart recorder, on display simultaneously. Hence the user should assume that the combined signals are setting the set point for an unseen secondary controller, even though the terminology "valve" is used for the final control element.

1. RUNNING THE PROGRAM AND PREPARATORY

Start **Windows**.

Run **PC-ControLAB**.

After the main operations display appears, if the Generic model is not being used (check left hand end of top line), press **Process | Select Model**. Highlight "Generic.mdl" and press **Open**.

Select **Control | Select Strategy | Forward Decoupling.**

The simulation is of an interacting process with two PVs of interest, a "temperature" and an "auxiliary temperature". Two disturbances are "feed rate" and "steam pressure". Feed rate has a significant influence on temperature and a lesser influence on auxiliary temperature. Steam pressure has a significant influence on both PVs. The exercise will demonstrate that both controller outputs significantly affect both PV's.

(Figure 1 refers to PV-1 and PV-2. Due to the arrangement of the Builder model configuration program, the second PV is referred to as PV-3 on the display. Please ignore that bit of inconsistency.)

The initial operational display contains two controllers, Controller 1 (Temperature) and Controller 2 (Auxiliary Temperature). Select either controller, and press **TUNE** , then on the Tuning display, select the **Decouple** tab. Note that this presents a table of decoupling element tuning parameters. There are four decoupling elements:

Controller 1 to Valve A
Controller 1 to Valve B
Controller 2 to Valve A
Controller 2 to Valve B

Each decoupling element consists of a gain term plus the dynamic compensation elements (like feedforward), lead-lag plus dead time.

These decoupling elements are used in pairs. The default configuration is for the "straight through" elements (Controller 1 to Valve A and Controller 2 to Valve B) to have a gain of 1.0 and no dynamic compensation: the "cross" elements (Controller 1 to Valve B and Controller 2 to Valve A) to have 0.0 for all tuning values. Therefore the default configuration of the control strategy is with no decoupling..

Press **Clear** to remove the tuning dialog box.

2. DEMONSTRATION OF PROCESS INTERACTION

2.1 Process Testing

To make the graphical interpretation of results easier, we will remove some of the strip chart traces. Select **View** from the Menu Bar, then **Variable Plot Selection**. Select NO for Load-1 and Load-2, then press **Clear**.

With both controllers in Manual, select Controller-1 (Temperature) and make a 10% (of full scale) increase in controller-1 output. (Due to the default decoupling parameterization, this is equivalent to making a 10% change in Valve-A position, with no change in Valve-B.)

Observe the effect on **both** measurement values (you might observe slightly different values from those tabulated below):

	Valve-A to PV-1	Valve-A to PV-2
Change in measurement (Percent of span)	15%	10% .
Change in controller output	10%	10% .
Process gain	1.5	1.0 .
Approx. dead time	2.0 mins	2.4 mins .
Approx. time constant	7.0 mins	1.5 mins .

Write this data as transfer functions:

$$\frac{1.5\ e^{-2.0\ s}}{7.0\,s+1} \qquad \frac{1.0\ e^{-2.4\ s}}{1.5\,s+1}$$

Return the output of Controller-1 to its original value. When the PVs have reached equilibrium, select Controller-2 and make a 10% increase in controller-2 output. (Due to the default decoupling parameterization, this is equivalent to making a 10% change in Valve-B position, with no change in Valve-A.)

Observe the effect on **both** measurement values (you might observe slightly different values from those tabulated below):

	Valve-B to PV-1	Valve-B to PV-2
Change in measurement (Percent of span)	-8.0%	13.3%
Change in controller output	10%	10%
Process gain	-0.8	1.33
Approx. dead time	2.8 mins	2.0 mins
Approx. time constant	5.0 mins	1.5 mins

Write this data as transfer functions:

$$\frac{-0.8\ e^{-2.8\ s}}{5.0\,s+1} \qquad\qquad \frac{1.33\ e^{-2.0\ s}}{1.5\,s+1}$$

Return the output of Controller #2 to its original value.

We have demonstrated that each controller output affects both PVs; that there is interaction in the process.

2.2 Testing of Each Control Loop Individually

Use the "Valve-A to PV-1" data to calculate feedback controller tuning parameters (proportion and integral only) for Controller-1. (Use the Open Loop Test table of equations in Laboratory Exercise 3.)

Use the "Valve-B to PV-2" data to calculate feedback controller tuning parameters for Controller-2.

	Controller-1	Controller-2
Gain	2.1	0.5
Reset (min/rpt)	6.67	6.67

Enter these parameters into the respective controllers.

Put both controllers in Manual and verify or set:

Controller-1 output	35.0
Controller-2 output	45.0

When the process reaches equilibrium, put the Controller-1 (Temperature) in AUTO and increase the set point by 10% of span. Observe the response of measurement-1. (Disregard any effect on measurement-2.) If the loop is relatively well tuned, the proceed. Else make adjustments to the tuning parameters until you get a satisfactory response from this loop, with the other loop in Manual.

Is measurement-2 affected by the control action of Controller-1? Yes .

Return Controller-1 SP to its original value. When both loops are in equilibrium, put Controller-1 in MANUAL and Controller-2 in AUTO. Increase Controller-2 set point by 10%. Make tuning parameter adjustments, if necessary, until you get a satisfactory response from this loop, with the other loop in Manual. A better set of tuning parameters for Controller-2 is

		Controller-2
Gain	=	0.67
Reset	=	3.2

Enter these values for Controller-2 and repeat the set point change.

Is measurement-1 affected by the control action of Controller-2? Yes .

Return Controller-2 set point to its original value.

We have demonstrated that each controller can be tuned to give satisfactory response when the other controller is in Manual. Both PVs are affected when either set point is changed.

2.3 Testing of the Combined Control System, with No Decoupling

Put both controllers in Automatic.

Make a 5% set point increase to controller-1. (Be prepared to put the controllers back in Manual if the loops tend to go unstable!)

Does the system tend to oscillate more or less than with one controller on Manual? More .

The usual approach, when faced with interacting control loops (without decoupling) is to change the tuning of one or both controllers until acceptable response is achieved. Usually the gain is reduced and the reset action is made slower, although this is not always the case. For this exercise, the following set of parameters gives reasonable response when both controllers are on AUTO.

	Controller-1	Controller-2
Gain	1.0	0.4 .
Reset (min/rpt)	8.0	3.0 .

You should observe that the interaction definitely affects the controller tuning when both loops are on automatic. Depending upon the form of the interaction, it may make the loops either more or less oscillatory. In lieu of formal decoupling, you can decouple the loops in the time domain by making one loop respond much slower than the other; that is, significantly reduce its gain and/or increase its integral time.

2.4 Calculating Decoupling Parameters

From the test data (transfer functions), calculate the required parameters for decoupling elements "Controller-1 to Valve-B" and "Controller-2 to Valve-A"

$$\text{Controller-1 to Valve-B} = \frac{\text{Valve-A to PV-2}}{\text{Valve-B to PV-2}}$$

$$= -\frac{\dfrac{1.0\,e^{-2.4\,s}}{1.5\,s+1}}{\dfrac{1.33\,e^{-2.0\,s}}{1.5\,s+1}} = -0.75\,\frac{1.5\,s+1}{1.5\,s+1}\,e^{-0.4\,s}$$

$$\text{Controller-2 to Valve-A} = \frac{\text{Valve-B to PV-1}}{\text{Valve-A to PV-1}}$$

$$= -\frac{\dfrac{-0.8\,e^{-2.8\,s}}{5.0\,s+1}}{\dfrac{1.5\,e^{-2.0\,s}}{7.0\,s+1}} = 0.53\,\frac{7.0\,s+1}{5.0\,s+1}\,e^{-0.8\,s}$$

Put both controllers in Manual
Record and enter the decoupling parameters.

	K_{dc}	T_{ld}	T_{lg}	D_{tm}
CONT-1 to VALV-B	-0.75	1.5	1.5	0.4
CONT-2 to VALV-A	0.53	7.0	5.0	0.8

(Be sure to enter 0.8 and 0.4 for dead time, not -0.8 and -0.4. Also, since the lead and lag times for the first decoupler element are the same, it is not necessary to enter them. It is recommended that you do so, however, in the event that one of them would require subsequent change.)

2.5 Testing the Combined Control System, with Full Decoupling

After entry of parameters, put both controllers in Auto and make a 10% set point change to Controller-1.

How much was measurement #2 affected? Slightly .

Make a 10% set point change to Controller #2.

How much was measurement-1 affected? Slightly .

Return the set points to their original values, then observe the response to a set point change of each loop when the other controller is in Manual.

Note that neither control loop has the same "feel" as it did before decoupling was implemented and the loops appropriately tuned. To recall this response, put both loops in Manual, then reenter the tuning parameters used in section 2.2

	Controller-1	Controller-2
Gain	2.1	0.67 .
Reset (min/rpt)	6.67	3.2 .

Put each loop in Auto (with the other in Manual) and make a set point change.

Is the response the same as it was before we changed the feedback controller tuning parameters.

No

The problem of changing feedback controller tuning parameters with and without decoupling is inherent in the FORWARD DECOUPLING control strategy, and is one of the advantages of the INVERTED DECOUPLING control strategy, covered in Demonstration Exercise 20