Date: ________________ Name: ___________________________________

DEMONSTRATION EXERCISE 20
INVERTED DECOUPLING CONTROL

OBJECTIVE: To become familiar with implementation another form of decoupling, “inverted” decoupling, and of the advantage of decoupling interacting control loops.

PREREQUISITE: Completion of Exercise

19 Forward Decoupling

BACKGROUND: See Demonstration Exercise 19 for background information on interacting processes in general, and on the need for decoupling..

Two forms of decoupling are called “forward” and “inverted”. This exercise illustrates inverted decoupling. Demonstration Exercise 19 illustrates forward decoupling.

See the following reference:

Wade, Harold L., *Inverted Decoupling, a Neglected Technique,* ISA Transactions, Vol.36, . 1, pp. 3-10, 1997

for additional information on inverted decoupling. This reference cites the following advantages of inverted decoupling over forward decoupling:

(1) The apparent process, as seen by each controller when decoupling is implemented, is the same as if there were no decoupling present and the alternate controller were in the manual mode.

(2) If the process inputs are implemented as cascaded set points to lower level flow controller, as is often the case, then the input signals to the decoupling elements can be derived directly from the flow transmitter outputs. Each decoupled control loop is then immune to abnormalities (e.g., valve at a limit or secondary controller in manual) in the secondary of the opposite control loop.

(3) Inverted decoupling can often be implemented in a DCS using PID function blocks with feedforward input. This will automatically provide such features as initialization and bumpless transfer between manual and automatic.

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

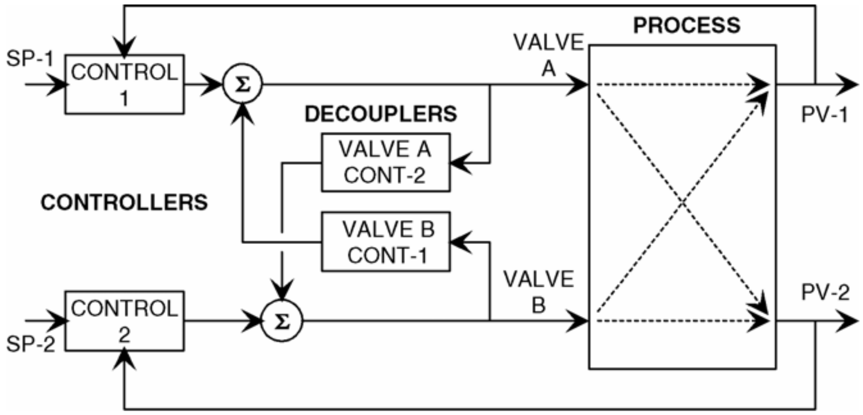

Figure 1
INTERACTING PROCESS WITH INVERTED DECOUPLING

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. Also, the input to a decoupling element may originate from the PV of the secondary controller.

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 | Inverted Decoupling**.

See Exercise 19 for a description of the process being simulated.

The initial operational display contains two controllers, Controller 1 (Temperature) and Controller 2 (Auxiliary Temperature). In addition to the usual AUTO and MAN buttons, each controller has an additional button labeled DKPL. This button has toggle action to switch on or off the signal from the opposite path decoupling element. See Figure 1. This switch is identical in function to the FFWD button on the face of the primary controller for the Feedforward control strategy. For now, leave the DKPLR off. (The LED labeled "DKPL" should be dark green.)

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 two decoupling elements:

Valve A to Controller 2
Valve B to Controller 1

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

The default tuning for these elements is a gain of 0.0 and no dynamic compensation values. Thus in the default tuning, there is no decoupling.

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

2. USER DETERMINATION OF DECOUPLING PARAMETERS

2.1 Process Testing

Since this is the same process as was used in Demonstration Exercise 13, the process tests will not be repeated here. (If you have not demonstrated the process testing, you may wish to conduct Section 2.1 of Exercise 19 at this time.)

In Exercise 19, the following transfer functions were determined.

Valve-A to PV-1: $\dfrac{1.5\ e^{-2.0\ s}}{7.0\,s+1}$

Valve-A to PV-2: $\dfrac{1.0\ e^{-2.4\ s}}{1.5\,s+1}$

Valve-B to PV-1: $\dfrac{-0.8\ e^{-2.8\ s}}{5.0\,s+1}$

Valve-B to PV-2: $\dfrac{1.33\ e^{-2.0\ s}}{1.5\,s+1}$

2.2 Testing of Each Control Loop Individually

Enter the following tuning parameters which were used in Exercise 19, Section 2.2

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

Put Controller-1 (Temperature) in AUTO, with Controller-2 (Auxiliary Temperature) in MAN. Both decouplers should be OFF. Increase the set point of Controller-1 by 10% of measurement span.

Is Controller-1 acceptably tuned? Yes .

Was PV-2 affected? Yes .

Return Controller-1 set point to its initial value. Put Controller-1 in MAN and Controller-2 in AUTO. Increase the set point of Controller-2 by 10% of measurement span.

Is Controller-2 acceptably tuned? Yes .

Was PV-1 affected? 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. This is identical to an observation made in Exercise 13.*

2.3 Testing of the Combined Control System, with No Decoupling

The system was demonstrated with both controllers in AUTO (and no decoupling) in Section 2.3 of Exercise 19. It need not be repeated here.

2.4 Calculating Decoupling Parameters

Decoupling parameters for inverted decoupling are calculated in the similar manner as the decoupling parameters for forward decoupling.

$$\begin{matrix}\text{Valve A}\\\text{to}\\\text{Controller 2}\end{matrix} = \frac{\begin{matrix}\text{Valve-A}\\\text{to}\\\text{PV-2}\end{matrix}}{\begin{matrix}\text{Valve-B}\\\text{to}\\\text{PV-2}\end{matrix}}$$

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

$$\begin{matrix}\text{Valve B}\\\text{to}\\\text{Controller 1}\end{matrix} = \frac{\begin{matrix}\text{Valve-B}\\\text{to}\\\text{PV-1}\end{matrix}}{\begin{matrix}\text{Valve-A}\\\text{to}\\\text{PV-1}\end{matrix}}$$

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

Record and enter the decoupling parameters.

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

2.5 Testing the Combined Control System, with Full Decoupling

After entry of parameters, and with both controllers in Auto and both decouplers activated, make a 10% set point change to Controller-1. (The controller tuning parameters set in Section 2.2 should still be in use.)

How much was measurement-2 affected? Insignificant

Was there an acceptable response of Controller-1? Yes

Return Controller-1 set point to its original value. When the PVs have settled, change Controller-2 set point by 10%.

How much was measurement-1 affected? Slightly .

Was there an acceptable response of Controller-2? Approximately

Observe the signals to the valves. Although these signals look “funny”, this is normal behavior for inverted decoupling if dynamic compensation is used.

Return Controller-2 set point to its original value.

You should have observed that inverted decoupling very effectively decouples the control loops; furthermore, the feedback controller tuning parameters did not have to be changed when decoupling was applied. This is in stark contrast to forward decoupling (see Exercise 13D) where the controller tuning parameters had to be significantly modified when decoupling was applied.

2.6 A Warning About Inverted Decoupling

Although inverted decoupling has several advantages over forward decoupling, as cited in “Background”, there are possible problems with

Realizability (Does a decoupling element require *future* values of an input signal?)

Stability (Is the inner loop created by the decoupling elements unstable?)

Robustness (How sensitive is the inverted decoupling technique to process model mis-match?)

We will consider only the stability question here. The reference cited in “Background” shows that if the inverted decoupling elements (for a 2 X 2 process) are implemented as gain/lead-lag/dead time elements, as is done in this exercise, then the question of stability is one of the location of the solutions in the complex plane of the equation:

$$\frac{K\,(T_{1A}\,s+1)(T_{2B}\,s+1)}{(T_{1B}\,s+1)(T_{2A}\,s+1)}e^{-T_d\,s} = 1 \qquad (1)$$

where T_{1A} is the time constant from Valve-A to PV-1
T_{2A} is the time constant from Valve-A to PV-2
T_{1B} is the time constant to from Valve-B to PV-1
T_{2B} is the time constant to from Valve-B to PV-2

$T_d = T_{d1B} - T_{d1A} + T_{d2A} - T_{d2B}$

T_{d1A} is the dead time between Valve-A and PV-1
T_{d2A} is the dead time between Valve-A and PV-2
T_{d1B} is the dead time between Valve-B and PV-1
T_{d2B} is the dead time between Valve-B and PV-2

$$K = \frac{K_{1B}\,K_{2A}}{K_{1A}\,K_{2B}}$$

K_{1A} is the process gain between Valve-A and PV-1
K_{2A} is the process gain between Valve-A and PV-2
K_{1B} is the process gain between Valve-B and PV-1
K_{2B} is the process gain between Valve-B and PV-2

Since these values are used for determining decoupling parameter values, in concept equation (1) can be solved in advance to determine whether or not the decoupling loop will be stable. This is a transcendental equation, however, so hand solution is not feasible. However an iterative solution, implemented in a computer, is feasible.

In the inverted decoupling scheme implemented in **PC-ControLAB**, when you press **Clear** to clear the Decoupler Tuning Entry box, the program automatically calculates the stability indicated by your parameter values. If instability is indicated, a warning is given, and a response is requested as to whether or not to proceed. (This is a special feature of **PC-ControLAB**. Commercial control systems do **not** have this feature!)

To demonstrate:

Put both controllers in MANUAL, but leave both decouplers ON.

Press **TUNE**, then select the **Decouple** tab. Confirm that the parameter values listed in Section 2.4 are still in place.

Select "Lead Time, Valve-A to Controller-2" and change its value from 1.5 to 3.0. Press **Clear**.

Notice that stability limits have been calculated for K, and that the value for K falls outside these limits. Therefore the prediction is that the decoupling loop will be unstable.

Press **YES** so you can see the effect.

Verify that both decouplers ON but leave the feedback portion of both controllers in MANUAL. (The LED's on each controller, from top to bottom, should be Light Green / Dark Green / Bright Red.)

Select Controller-1 and change its output by 10%.

You should observe that, even with both controllers in manual, there is a growing excursion of the controller outputs. This is due to the instability of the loop created by the decoupling elements, and has nothing to do with the tuning of the feedback controllers themselves.