Date: ________________ Name: ___________________________________

LABORATORY EXERCISE 17
CHARACTERISTICS OF MULTIPLICATIVE FEEDFORWARD CONTROL

OBJECTIVE: To view the advantage of multiplicative feedforward control in non-linear situations where the best choice of manipulated variable is the ratio between the load and the controller input.

PREREQUISITE: Completion of Exercises

5	Temperature Control Loop Characteristics
14	Characteristics of Ratio Control
16	Characteristics of Additive Feedforward Control

REVIEW: In Exercise 16 it was mentioned that there are two methods of combining feedback and feedforward control:

1) by *adding* the feedforward and feedback controller outputs
2) by *multiplying* the feedforward and feedback controller outputs.

In Exercise 16, additive feedforward control was demonstrated, using a process heater as a vehicle for instruction. It was demonstrated that if the operating conditions (in this case, set point and process flow rate, representing the load on the process) do not vary greatly from their nominal values, then additive feedforward is satisfactory. However, it was also demonstrated that due to the non-linear nature of the process which causes the process gain (as well as the dead time and time constant) to increase as the process flow rate decreases, then additive feedforward becomes unsatisfactory at low loads. This is due to the fact that the feedback control loop becomes increasingly oscillatory, and even perhaps unstable, at low process flows.

This laboratory exercise demonstrates how multiplicative feedback control overcomes this problem, so the the feedback loop behavior is relatively constant at all process flow rates.

1. RUNNING THE PROGRAM

Start **Windows**.

Run **PC-ControLAB**.

2. FEEDFORWARD CONTROL SET UP

Select **Control | Select Strategy.** Click on “Feedforward_Multiply” from the drop-down menu.

Select **Process | Select Model.** Highlight “Heater” and click on **OPEN.**

The Primary controller (labeled “Temperature”) is an ordinary feedback controller with the usual Manual and Auto switches.

The Secondary controller (labeled “Fuel Flow”) contains both a feedback section and a feedforward section. (Note that in contrast to Additive Feedforward, where the feedforward function was built in to the Primary controller, with Multiplicative Feedforward, *the feedforward function is built in to the Secondary controller.*

The Secondary controller can be operated in one of four modes:

Manual ("MAN" LED bright red. All others dark green.) The operator sets the manual output signal to the valve. The Secondary controller SP tracks the PV. The Primary controller outputs tracks the ratio of Fuel (Secondary PV) to Process Flow (Primary Load).

Automatic ("AUTO" LED bright green. All others dark red or dark green.) The operator can set the Secondary controller SP for automatic operation. The Primary controller output tracks the Secondary controller PV.

Cascade ("AUTO" and "CASC" LEDs bright green. "MAN" LED dark red. "FFWD" LED dark green.) In this mode, the Secondary controller acts as the normal secondary in a cascade loop. Its set point comes directly from the Primary output. If the Primary controller is in Manual, the Primary controller output can be adjusted to adjust the set point of the Secondary controller.

Feedforward ("AUTO", "CASC" and "FFWD" LEDs are all bright green. "MAN" LED is dark red.) In this mode, the output of the Primary controller, being the required ratio between load and Secondary PV, is multiplied by the load (process flow); the product becomes the set point for the feedforward section of the Secondary controller.

The user can go from	*Manual*	*to*	*Auto*	*(Press "Auto")*
	Manual	*to*	*Cascade*	*(Press "Cas/FF")*
	Auto	*to*	*Manual*	*(Press "Man")*
	Auto	*to*	*Cascade*	*(Press "Cas/FF")*
	Cascade	*to*	*Manual*	*(Press "Man")*
	Cascade	*to*	*Auto*	*(Press "Auto")*
	Cascade	*to*	*Feedforward*	*(Press "Cas/FF" again)*
	Feedforward	*to*	*Manual*	*(Press "Man")*
	Feedforward	*to*	*Auto*	*(Press "Auto")*
	Feedforward	*to*	*Cascade*	*(Press "Cas/FF" again)*

To reduce the number of signals recorded, select **View | Variable Plot Selection.** Then select **NO** for Out-2. Select **YES** for Out-1.

Enter the following tuning parameters for the Secondary controller:

Gain:	0.5
Reset:	0.15 minutes/repeat

With the Secondary controller selected, press **Tune** then select the **Feedfwd** tab.

Enter the tuning parameters determined in Section 5 of Laboratory Exercise 16.

T_{ld} = __________

T_{lg} = __________

T_{dt} = _________

Don't worry about K1 and K2. They are used for a different purpose. Why is there no K_f? Because the ratio set by the primary controller output, Secondary SP to Load (Fuel to Process Flow Rate) is the multiplicative counterpart to K_f as used in additive feedforward.

For the Primary controller, enter the final feedback tuning parameters determined in Section 6 of Laboratory Exercise 16.

Gain = ____________

Reset = ____________ minutes/repeat

Put the Secondary controller in Cascade (press **Cas/Ff**), then into Feedforward (press **Cas/Ff** again.)

Put the Primary controller in Automatic.

Note: Fuel flow (Secondary PV) ____________KCFH_ = _______%_

Process flow (Primary Load) _____________GPM_ = _______%_

Ratio, fuel flow-to-process flow (% to %) ________________

Convert this fraction to a percent ___________%___

Primary controller output (Select the Primary controller, press **View | Data Monitor**.)

___________%___

This demonstrates the fact that the Primary controller output (when 0 – 100% is converted to a fraction) is setting the ratio of secondary flow to load. When the Primary controller output is 100%, then it would be calling for equal percentage flow rates.

What if we wanted to give the Primary controller output a wider range than that? For instance, if we wanted to let Primary controller output of 50% represent a required 1/1 (percentage) ratio; then a 100% output would represent a required 2/1 (percentage) ratio. If the Secondary PV and load flow transmitters are spanned appropriately, then in normal operation the Primary controller output run somewhere near mid scale.

Select the Secondary controller. Press **Tune** then select the **Feedfwd** tab. Enter a new value for K1.

K1 = 2.0

Note the new Primary controller output. __________%___

Changing K1 caused the Primary controller output to be reinitialized so that it is now only one-half its former value.

Since changes in Primary controller output have made it twice as effective as it was prior to changing K1, we have to make a compensating change to the Gain of the primary controller.

Select the Primary controlller and press **Tune**. Set a new Gain to half the present value.

Gain = __________

4. TESTING THE CONTROL LOOP

The Primary controller should be in Auto with a set point of 275^0. Its output should be 18.67%. The Secondary controller should be in Feedforward. Its set point should be 28.0 KCFH (28%) and its output 35%. The process flow (primary load) should be 300 GPM (75%). If all these conditions are true, proceed.

Select the Primary controller and increase process flow by 5% (press **StepIncr** once).

Is the response to a load change OK? ___________

Change the process flow back to its original value, then change the set point to 300^0.

Is the response to a set point change OK? ___________

We've tested the response near the normal operating point and found it to be okay. Additive feedforward did that much for us. How about when we are far away from normal operating point, say at high or low process flow rates?

Increase the process flow, one step at a time, to 95%.

As you made each step, was the response to the load change OK? ___________

Change the set point to 275^0.

At this high process flow rate, is the response to set point change OK?___________

Decrease the process flow, one step at a time, to 25%.

At each step, does the loop look like it is going to be unstable? ___________

What happened using Additive Feedforward (Laboratory Exercise 10) at low process flow rates?

____

Is the response to a load change as good as it was at the normal operating point of 75% load?

____

Explanation: We have said that for a process heater, the process gain, dead time and time constant all increase as the process flow rate decreases. The most severe effect is the change in process gain. The changes in dead time and time constant are not so severe, because the ratio of these stays approximately constant.

The change from additive feedforward to multiplicative feedforward took care of the change in process gain. We computed the dynamic parameters of the feedforward controller from tests made at the normal operating point and these have not been changed. Hence the dynamics of the feedforward controller are not quite correct for variations from the normal operating point. This inaccuracy usually does not seriously degrade the control loop performance, however, so that common practice is to leave them as fixed values. Conceptually, these could be changed by a scheduled tuning approach parameters. As far as is known, however, no commercial vendor offers this as a standard feature.