Solutions for Tutorial 15
Feedforward Control

Feedforward adds a new control approach that can significantly improve dynamic performance when properly designed and implemented. Recall that the **feedforward design criteria** provide the basis for the proper selection of feedforward; these criteria should be used during this tutorial.

15.1 For the processes in the following figure, determine whether feedforward control is possible, whether it will improve dynamic performance, and if yes to both, sketch the feedforward control on the figure.

Heat exchanger with by-pass flow: The controlled variable is the temperature and the manipulated variable is the split of the process flow between through the exchanger and the by-pass. The measured disturbance is the inlet temperature.

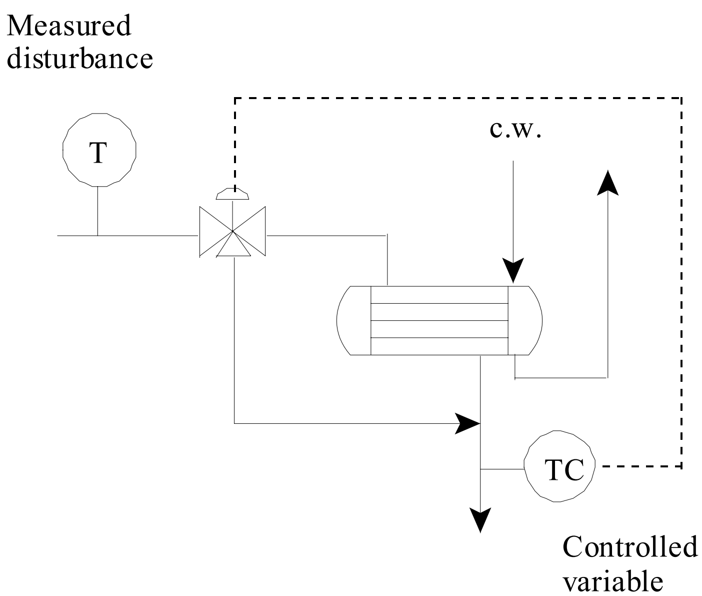
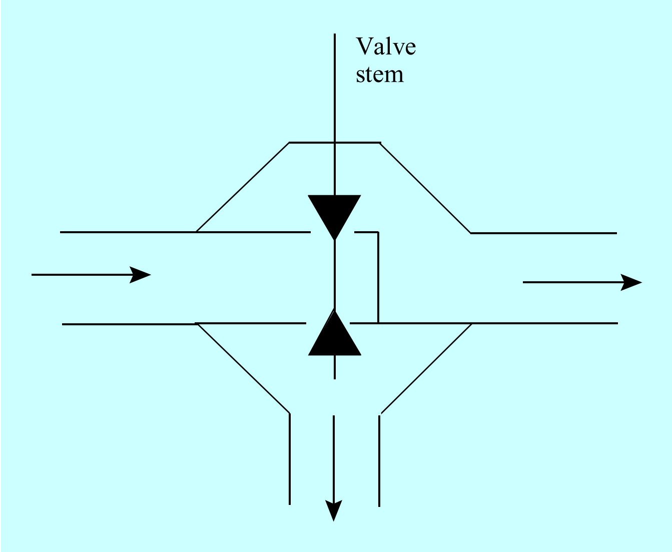


Figure 15.1. Heat exchanger.

First, let's discuss the process.

- **Does a causal relationship exist?** Certainly, the by-pass flow affects the outlet temperature after the mixing point; the greater the percentage by-passed, the warmer the controlled variable.

- **How does the three-way valve work**? The sketch shows two plugs attached to the valve stem. As the stem moves, both plugs move in the same direction. As a result, one opening for flow becomes larger, while the other opening becomes smaller. Each opening leads to a different flow path. In this example, one path is to the heat exchanger, and the other is to the by-pass.



Thus, one valve can split the flow in two different paths, while the total flow does not have to be changed.

Second, let's address feedforward control.

1. Is feedforward control possible? We refer to the **feedforward design criteria**. We conclude from the table that feedforward is possible.

1. Is feedback alone unsatisfactory	Discussed next
2. Measured feedforward variable	**Yes**
3. Variable indicates important disturbance	**Yes**
4. no relationship between manipulated and disturbance and feedforward variables.	**Yes**
5. Disturbance dynamics not faster than feedback	**Yes**

2. Is feedforward likely to improve control performance? The answer would be "yes" for a feedback control system that has dynamics that are difficult to control. These would include

- long dead time
- many and long time constants
- inverse response

However, the feedback system in this process involves mixing and a fast sensor. Therefore, the feedback dynamics are very fast.

Because the feedback dynamics are very fast, we expect the feedback performance to be very good. We would not recommend feedforward compensation for this process.

15.2 In this question, you will consider a packed bed reactor experiencing feed composition disturbances. The reactor shown in Figure 15.2 is similar to the process in textbook Example 15.1; however, the effluent composition is not measured, so that feedback is not possible. Determine whether feedforward control is possible and desirable. If yes to both questions, sketch the feedforward controller on the figure and derive the feedforward controller transfer function using the modelling information in textbook Example 14.1.

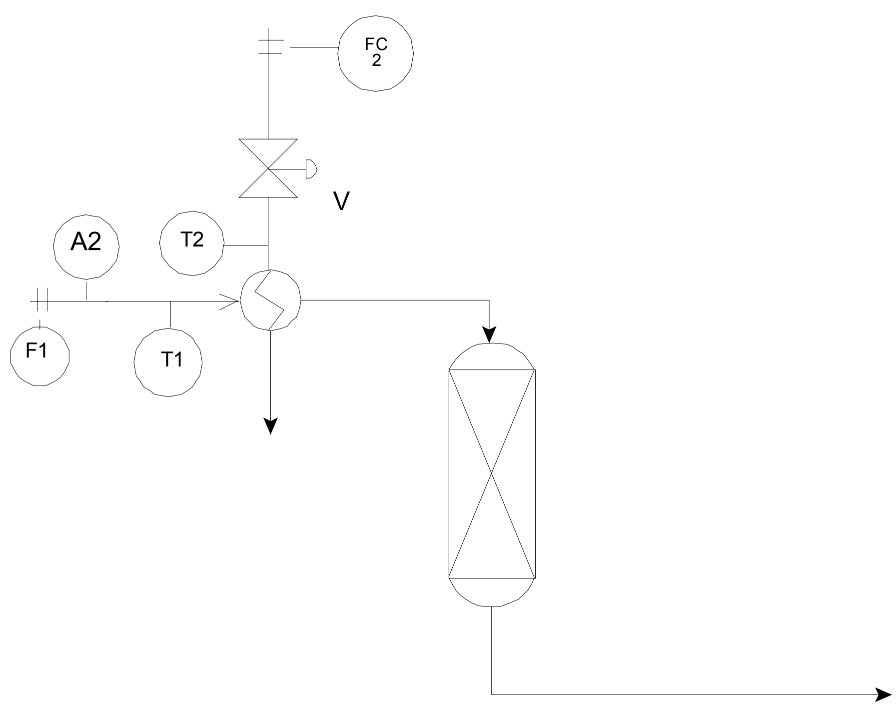
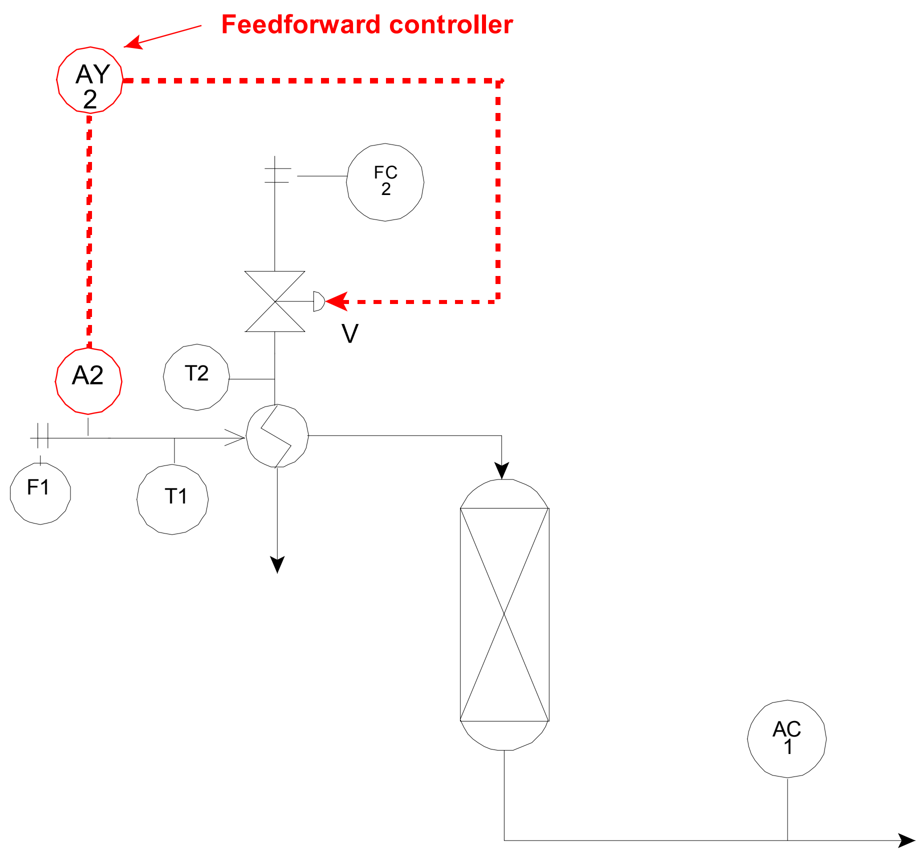


Figure 15.2 Packed bed Chemical reactor with feed composition disturbance.

To evaluate the possibility of feedforward, we refer to the **feedforward design criteria**.

1. Is feedback alone unsatisfactory	**Clearly, yes. Feedback control of effluent composition does not exist in this example**.
2. Measured feedforward variable	**Yes**
3. Variable indicates important disturbance	**Yes**
4. no relationship between manipulated and disturbance and feedforward variables.	**Yes**
5. Disturbance dynamics not faster than feedback	**Yes (no feedback)**

Therefore, we conclude that feedforward is possible. Also, we conclude that we should obtain a significant performance improvement because no composition feedback exists. We **recommend** feedforward in this situation.



15.3 You can use feedforward principles in everyday life, but not everywhere. Here, you can decide when to use feedforward in typical decisions.

Case	Decision	Controlled variable	Disturbance
a	Stock selection for investing	Maximum return	Cost of energy
b	Baking bread in an oven	Oven temperature	Room temperature
c	Driving an automobile	Position in lane	Bump in the road

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a. We can measure many events that affect world energy prices, such as discoveries of oil and gas, wars, political conflicts, and so forth. If we act quickly, we might gain an advantage. Feedforward could provide over feedback after energy prices change.

b. The room temperature has a very small effect on the oven temperature. Also, the room temperature is not likely to change rapidly. Feedforward is not recommended.

c. If we can see the bump before we hit it, we can take evasive action and miss the bump. Feedforward is recommended.

15.4 For feedforward control (used in conjunction with feedback), the sensor for the disturbance variable should provide good

☐ accuracy
☐ reproducibility ← **correct** ☺
☐ noise moderation

Note: Feedback would correct for a bias in the feedforward sensor. Feedforward only needs to correct for **changes** in the measured disturbance variable.

15.5 After feedforward control has been implemented, what changes should we make to the feedback controller tuning?

☐ make more aggressive because the controlled variable will stay in a narrow range
☐ make less aggressive because feedforward will "do most of the work"
☐ make no change ← **correct** ☺

Note 1: The feedforward controller does not change the feedback process dynamics. Therefore, the feedback controller tuning should not be modified.

Note 2: If the feedforward and feedback signals were multiplied, as it would if feedback were added to textbook figure 15.14, the feedback gain would be affected; therefore, the controller gain (K_C) should be modified. See textbook Section 16.3 and Figure 16.5.

