Name: ____________________________

(Adapted from notes by D. Clough at the University of Colorado, Boulder)

FeedForward Control

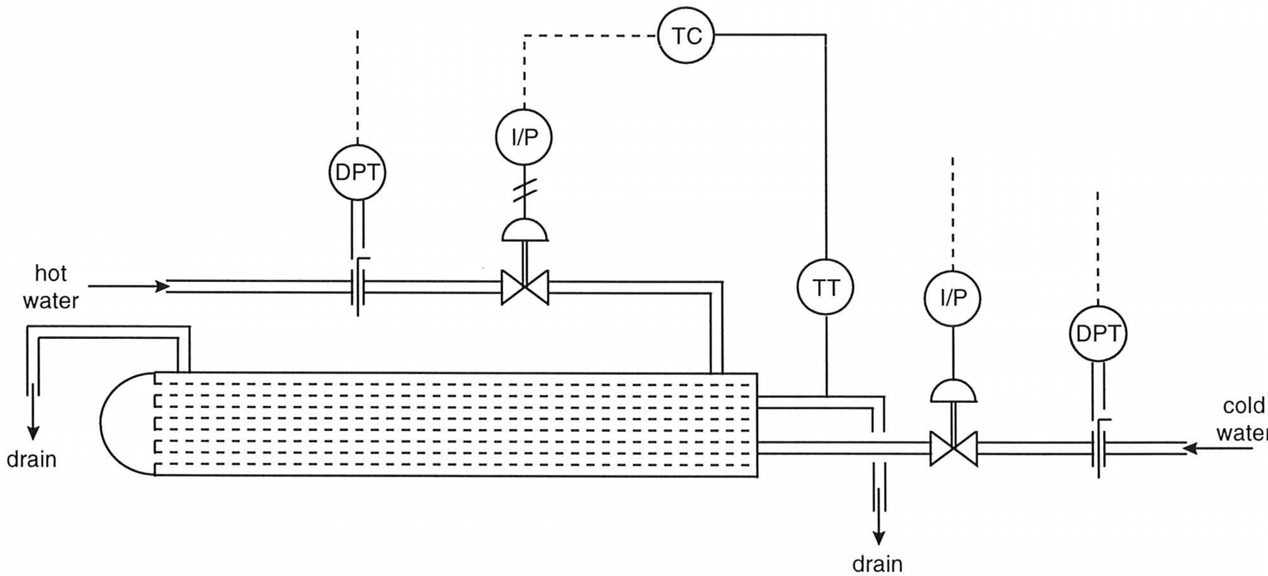
So far, most of the focus of this course has been on feedback control. In certain situations, the performance of control systems can be enhanced greatly by the application of feedforward control. What you need to look for are two key characteristics:

1) an **identifiable disturbance** is affecting significantly the measured variable, in spite of the attempts of a feedback control system to regulate these effects, and

2) this disturbance can be **measured**, perhaps with the addition of instrumentation.

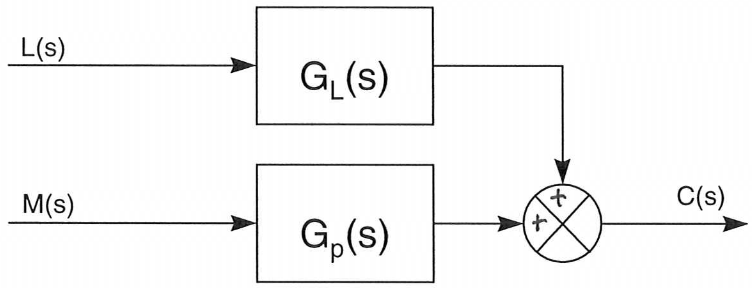
Also, we would be interesting in controlling the source of the disturbance locally, before it affects our main process, if that were possible. If it is possible, we would usually implement cascade control, not feedforward control.

As an example:



This is shown with a simple feedback controller in place. Cold water outlet temperature is controlled by manipulating the hot water flow rate. Imagine what happens when the cold water flow rate changes suddenly. Eventually, the cold water outlet temperature will change and the hot water flow rate will react via the temperature controller. By the time that happens, all of the cold water in the heat exchanger will be either too cold or too hot. If these changes in cold water flow rate are frequent and unpredictable, the performance of the feedback controller may not be satisfactory. So, we would then have an identifiable disturbance, and it happens that we have a measurement of the cold water flow rate. We have a candidate for feedforward control.

This situation, minus the feedback controller, can be represented by the block diagram below.



The diagram shows both the manipulated input, M(s), and the disturbance input, L(s), influencing the measured variable, C(s). This is shown in the form of a linear model, which will typically be an approximation to the actual behavior, i.e., a transfer function fitted to response test data.

The idea behind a feedforward controller is then simply: How do we manipulate M(s) to cancel the effect that L(s) will have on C(s)? Let's have you derive that.

1) Write an algebraic equation for the block diagram. That is,

C(s) = ____

2) If the measured variable, C(s), is to be unaffected by disturbances then

$c(t)$ will = $\bar{c}$

$\hat{c}(t)$ will = 0

and C(s) will = ________

3) Substitute this into the equation from step 1), and solve for M(s) in terms of L(s),

M(s) = ______________________________

This is the transfer function for a feedforward controller. If the disturbance in measured, L(s), this feedforward controller will determine how to manipulate M(s) to cancel the effect of L(s).

Next, we need to see what a typical feedforward controller actually amounts to, given $G_P(s)$ and $G_L(s)$.

Consider the common situation where we fit FOPDT models to the process and load transfer functions from test response data. Then,

$$G_P(s) = \frac{K_p e^{-\theta_p s}}{\tau_P s + 1} \quad \text{and} \quad G_L(s) = \frac{K_L e^{-\theta_L s}}{\tau_L s + 1}$$

Now, substitute these into your design equation for the feedforward controller and simplify the result.

$G_{FF}(s) =$ ____________________________

Under what conditions would this feedforward controller not be feasible?

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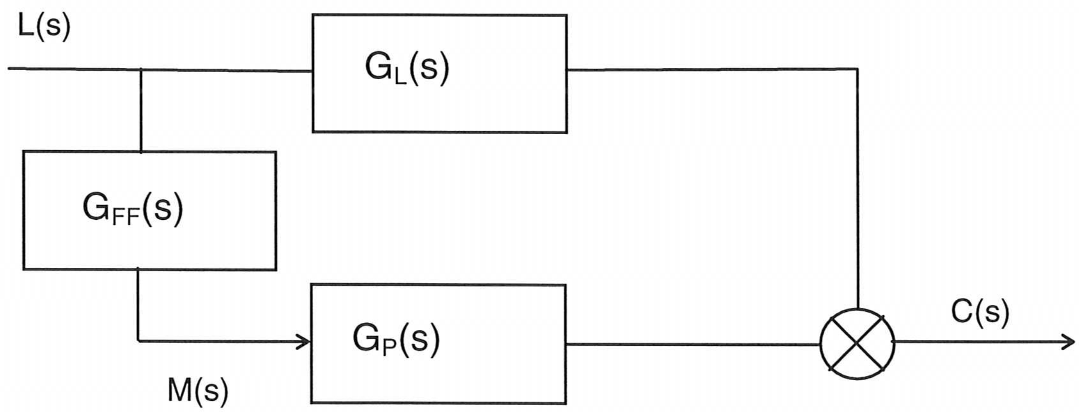
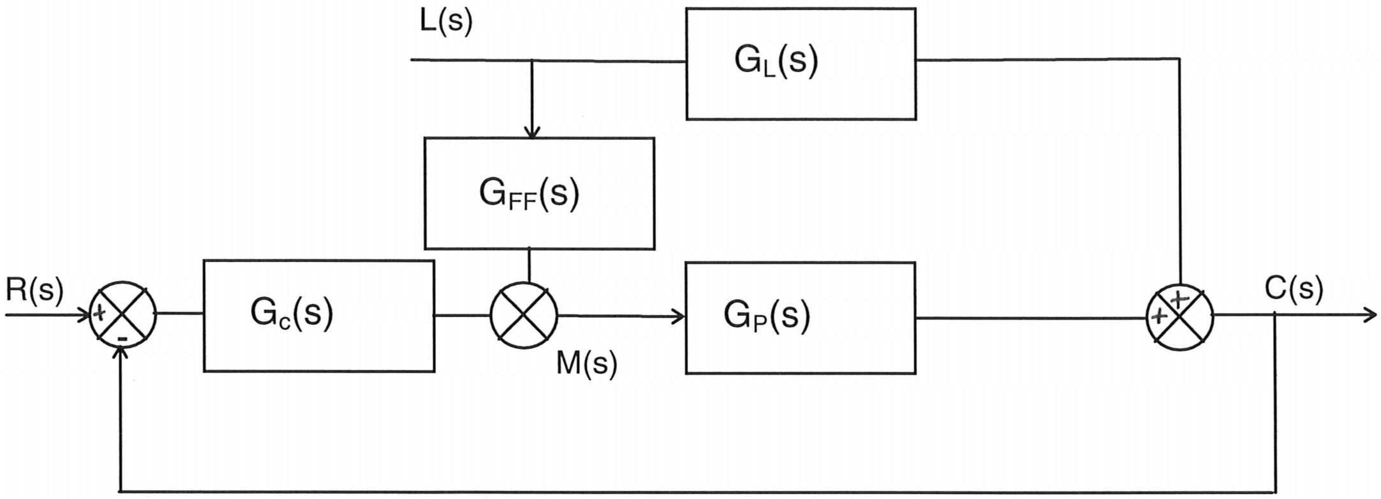
We can now modify the block diagram to include the feedforward controller.

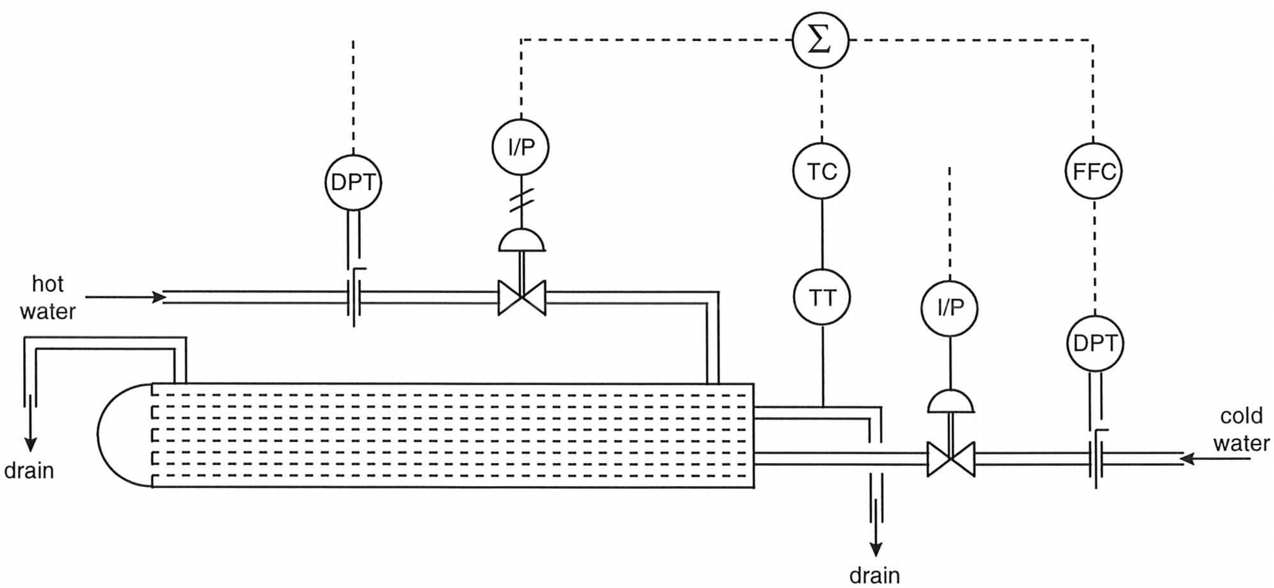


The performance of a feedforward controller depends on the accuracy of the models, $G_p(s)$ and $G_L(s)$, used to design it. It will never be perfect, and, of course, it does not compensate for disturbances that are not measured and acted on by the feedforward controller. Consequently, it is common to couple a feedforward controller with a conventional feedback controller. The block diagram for this is shown on the next page.



Note, in particular, that the outputs of the two controllers are simply added together.

If we modify the heat exchanger to include a feedforward-feedback control scheme, its diagram would look like



Qualitative Questions

1. What is a key advantage of feedforward control?

2. At the beginning of the semester we stated that feedforward control involved prediction of the effect of the disturbance. How is that prediction made? How important is the accuracy of the prediction?

3. Name a disadvantage of feedforward control.

Let's suppose that we have a process unit to which we would like to add feedforward control.

The transfer function that relates the controlled variable to the manipulated variable is:

$$\frac{C}{M} = G_P(s) = \frac{0.60e^{-37s}}{39s+1}$$

The transfer function that relates the controlled variable to the load variable is:

$$\frac{C}{L} = G_L(s) = \frac{0.25e^{-57s}}{31s+1}$$

From the transfer functions, determine the following quantities:

Ratio of gains: $\frac{K_L}{K_p} =$ ______________

Disturbance time constant: $\tau_L =$ ______________

Process time constant: $\tau_P =$ ______________

Difference in deadtimes: $\theta_L - \theta_P =$ ______________

These are the parameters needed for the feedforward controller. What is the transfer function of the resulting feedforward controller?

$G_{FF} =$ ____________________________________

Where did the transfer functions at the top of the page come from?

What is the minimum value that can be used for the difference in deadtimes? What implications does this have?