# Control System Synthesis - PhD Class

Handin 1: Temperature control in a heat exchanger

24/09/2020

A chemical reactor called "stirring tank" is depicted below. The top inlet delivers liquid to be mixed in the tank. The tank liquid must be maintained at a constant temperature by varying the amount of steam supplied to the heat exchanger (bottom pipe) via its control valve. Variations in the temperature of the inlet flow are the main source of disturbances in this process.

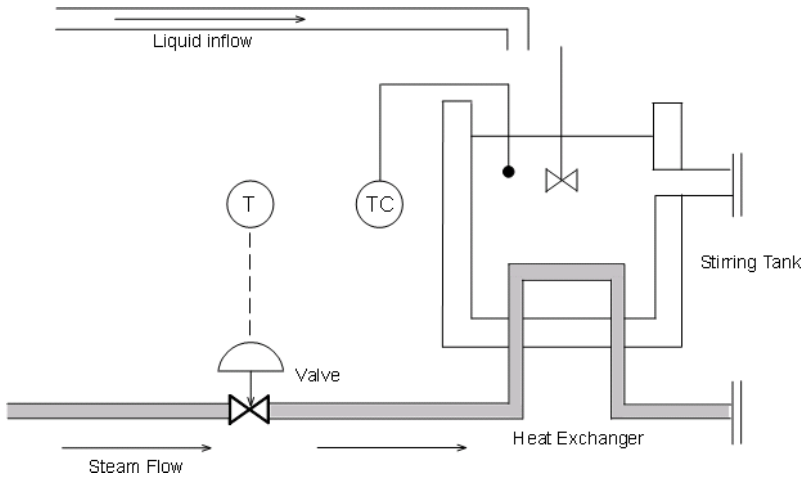


Figure 1: System to be controlled.

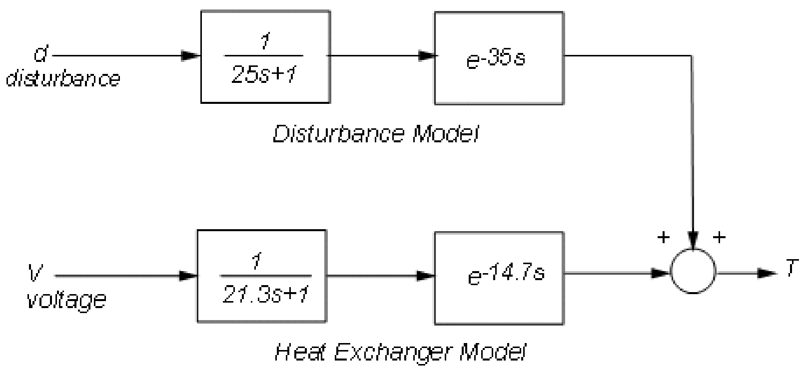


Figure 2: Diagram of the system.

The transfer function

$$G_p(s) = \frac{e^{-14.7s}}{21.3s + 1}$$

models how a change in the voltage V driving the steam valve opening affects the tank temperature T, while the transfer function

$$G_d(s) = \frac{e^{-35s}}{25s + 1}$$

models how a change d in inflow temperature affects T.

# 1 Feedback control

To regulate the tank temperature T around a given setpoint Tsp, we can use the following feedback architecture to control the valve opening through the voltage V:

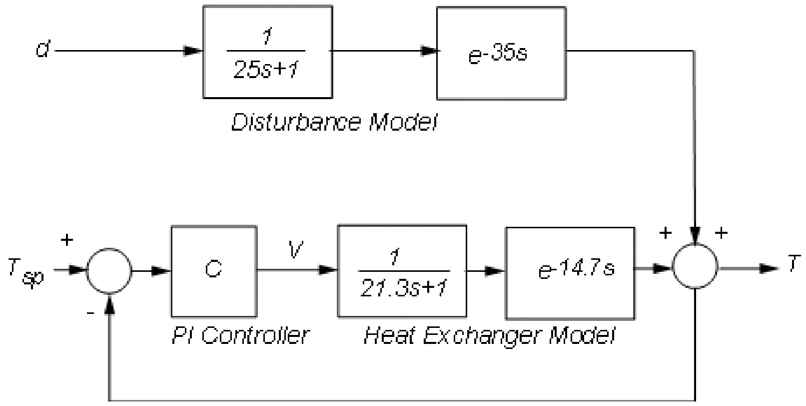


Figure 3: Feedback control for temperature regulation.

1. The first-order approximation of a time delay $e^{-\tau s}$ is $\frac{1-\tau s/2}{1+\tau s/2}$. Use this approximation to determine the performance limitations associated with a time delay.

2. Consider a P controller $C(s) = k_p$. What is the influence of $k_p$ on performances and robustness? Plot the Nyquist curves for different values of $k_p$ and the associated closed-loop step responses. Pick a value for $k_p$.

3. Let's move to a PI controller $C(s) = k_p + \frac{k_i}{s}$, where $k_p$ has the same value you chose previously. Choose $k_i$ to obtain good tracking performances (use the Nyquist curve, the closed loop Bode plot and step responses).

# 2 Feedforward control

Changes in inflow temperature are the main source of temperature fluctuations in the tank. To reject such disturbances, an alternative to feedback control is the feedforward architecture shown below. The feedforward controller $F$ uses measurements of the inflow temperature to adjust the steam valve opening: it therefore anticipates and preempts the effect of inflow temperature changes.

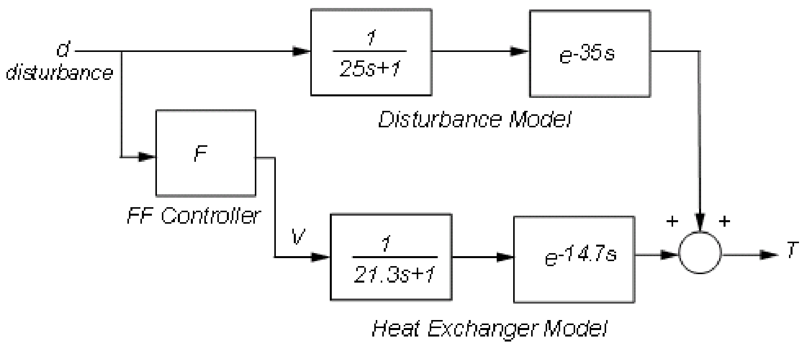


Figure 4: Feedforward control for disturbance rejection.

1. In this new configuration, what is the transfer from temperature disturbance d to tank temperature T?

2. How can you express perfect disturbance rejection on this transfer? What is the corresponding expression of the feedforward $F$?

3. In reality, modeling inaccuracies prevent exact disturbance rejection, but feedforward control will help minimize temperature fluctuations due to inflow disturbances. To get a better sense of how the feedforward scheme would perform, increase the ideal feedforward delay by 5 seconds and simulate the response to a step change in inflow temperature.

# 3 Combining feedback and feedforward

Feedback control is good for setpoint tracking in general, while feedforward control can help with rejection of measured disturbances. Next we look at the benefits of combining both schemes. The corresponding control architecture is shown below.

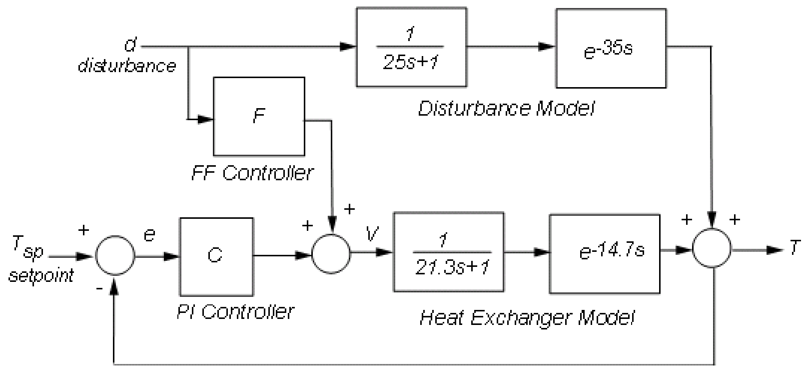


Figure 5: Combined feedback and feedforward control.

1. Express the transfers from the input vector $(T_{sp}, d)$ to the temperature $T$ in the feedback only case and in the feedback + feedforward case.

2. Compare these two designs based on the step response and the Bode plot.