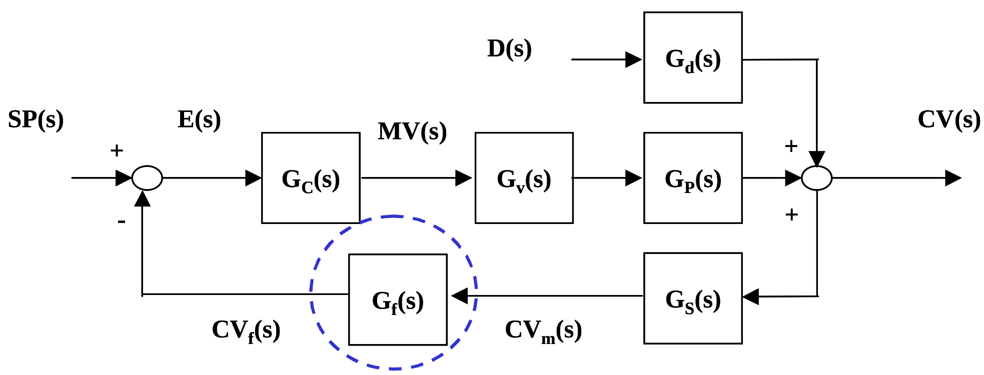
Solutions for Tutorial 12
Application Issues

12.1 A colleague states, "*A filter in a feedback control loop influences stability. In fact, it could cause instability when added to a loop that had been stable*." You are not sure that the statement is correct. Investigate the issue and determine whether the statement is true or false. Naturally, you will provide clear explanations and concise mathematical evidence.

We know that elements in the feedback loop affect stability. This can be demonstrated by showing that all elements in the characteristic equation of the closed-loop system affect stability.

The block diagram for a feedback loop with a filter is given in the following block diagram.



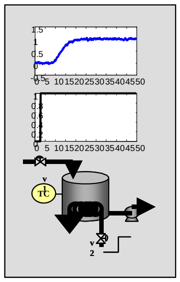
Clearly, the filter is in the feedback loop. In addition, the filter appears in the characteristic equation, as shown in the following transfer function.

$$\frac{CV(s)}{D(s)} = \frac{G_d(s)}{1+G_p(s)G_v(s)G_c(s)G_f(s)G_S(s)}$$

Therefore, the first part of the statement by your colleague is correct; a filter affects stability!

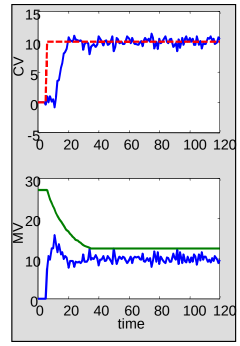
Is it likely that a filter will destabilize an otherwise stable loop? The answer depends upon the value of the filter time constant. The guideline is that the filter time constant should be small compared with the feedback dynamics, i.e., $\tau_f < 0.05\ (\theta+\tau)$. Let's look at an example; we will extend an example from Chapter 9 of the textbook, with the results in the chapter repeated in the following figure.

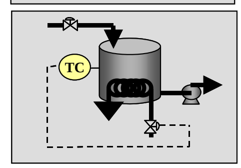
Process reaction curve



COMBINED DEFINITION OF TUNING

- **First order with dead time process model**
- **Noisy measurement signal**
- **± 25% parameters errors between model/plant**
- **PID controller: determine K_c, T_I, T_d**
- **Minimize IAE with MV inside bound**





Kp = 1

θ = 5

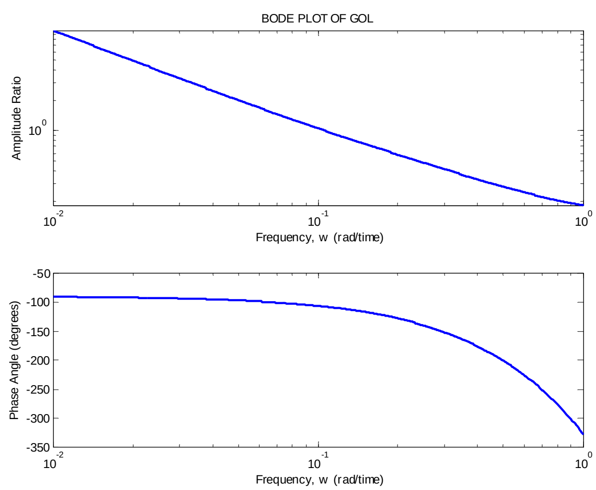
τ = 5

Kc = 0.74

TI = 7.5

Td = 0.90

We will evaluate the stability, i.e., the gain margin, without and with a filter. The Bode stability analysis gives the following results with the tuning in the figure and no filter.



The critical frequency is between 0.41382 and 0.41477
The amplitude ratio at the critical frequency is 0.32213

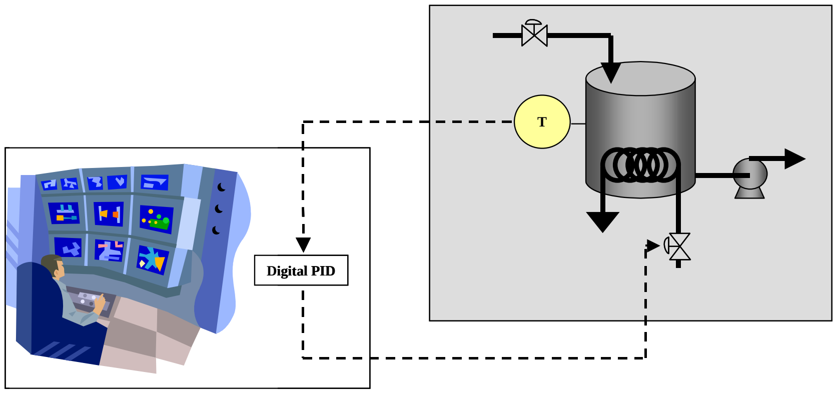
We repeat the calculation with a first-order filter with a time constant of 0.50. The plot is nearly the same and the numerical results are given in the following.

The critical frequency is between 0.3705 and 0.37135
The amplitude ratio at the critical frequency is 0.34543

We see that the amplitude is slightly higher; thus, the affect of the filter is to destabilize the system. However, the effect is minor (insignificant) when using the guideline that the maximum filter time constant is 5% of the feedback $t_{63\%}$.

Set filter time constant small compared to feedback dynamics, $\tau_f < 0.05\ (\theta+\tau)$

12.2 You have performed the controller tuning procedures described in Chapter 9 (process reaction curve for dynamics and correlations for tuning) for the stirred tank heater shown in Figure 12.2. The tuning is given below. Determine the scaled controller gain, proportional band and reset time, which might be required in a commercial controller.



$$E_s(t) = SP_s(t) - CV_s(t)$$

$$MV_s(t) = \frac{100}{PB}\left[E_s(t) + T_R \int_0^{\infty} E_s(t')dt' - T_d \frac{d\,CV_s}{dt}\right] + I$$

Figure 12.2

Kc = -2.1 K/% open TI = 8.1 minutes Td = 0.9 minute	Temperature sensor is 50-200 C The valve is fail closed

The hard work has been completed. Here, we simply need to "convert units". We use the following relationships.

$(Kc)s = K_c\ (CV_r)/MV_r)$
$PB=100/(K_c)_s$.
$T_R = 1/T_I$

For this example,

$(Kc)s = K_c\ (CV_r)/MV_r) = -2.1$ K/%open (150K)/(100 %open) = -3.15 (dimensionless)
PB = 100/|-3.15| = 31.7 (always positive)
$T_R = 1/T_I = 1/8.1 = 0.123$ repeats per minute

Let's recall that we have not changed anything in the controller or PID performance. However, we must observe the standards used in various commercial digital control software.

12.3 Consider the calculation of a digital first-order filter. Write pseudo-code for the initialization and normal execution of the filter.

The initialization should provide a smooth transition. Therefore, the first value of the filter output is set to the current measurement. On subsequent executions, the equation for the first-order filter is calculated.

```
%  pseudo-code for first order filter
%  the inputs are
%      the initialization flag  INIT = true for initialization
%      The current measured value (MeasV)
%
%  stored values
%      the previous filter output (PVN_1)
%      the filter constant alpha = 1 - exp (-Δt/τf)
%
%  output variable
%      the current filter variable (PVN)
%
% determine if initialization

IF INIT = true
      PVN   = MeasV;
      PVN_1 = MeasV;

END  % IF INIT

% Calculate the filter

PVN = alpha*MeasV + (1-alpha)*PVN_1;

PVN_1 = PVN;  % store for next iteration
```

12.4 The flash process introduced in Chapter 2 is shown in Figure 12.4. Determine the failure position for each of the control valves. We know that we must analyze the entire process, including sources and sinks for all flows, before determining the failure positions. For this exercise, consider only the equipment in the figure.

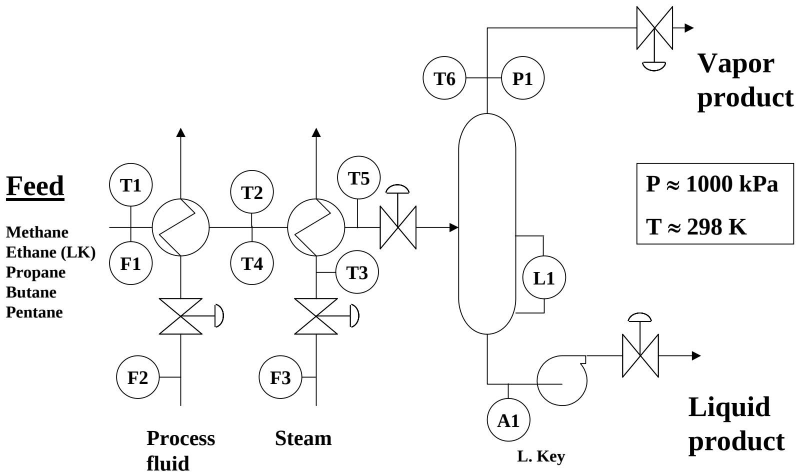
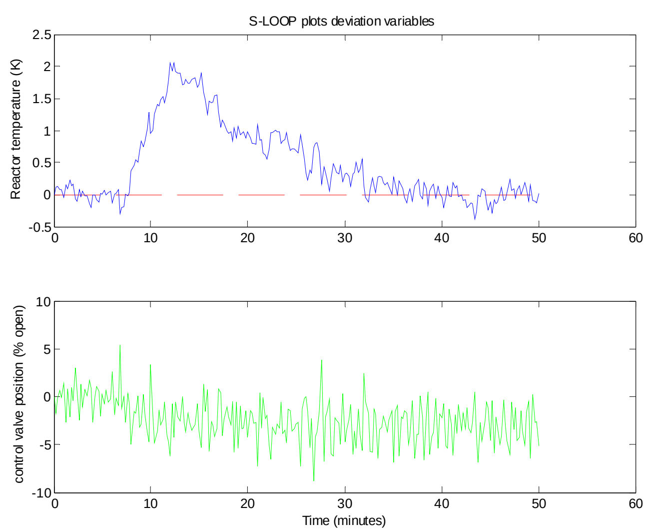


Figure 12.4

The failure positions are given in the following table along with a brief explanation.

Valve	Failure position	Explanation
Process fluid to heat exchanger	closed	Reduce heating to closed heat exchanger
Steam to heat exchanger	closed	Reduce heating to closed heat exchanger
Feed flow	closed	Reduce flow in of material to closed vessel
Vapor leaving drum	open	Prevent high pressure in closed vessel
Liquid leaving drum	open	Prevent high pressure in closed vessel (Note that this could lead to zero flow through a pump and flow to another closed vessel.)

12.5 Diagnose the performance of the closed-loop system using a PID controller. Suggest changes for improving the performance, if warranted.



First, we consider the CV performance, temperature. We have no knowledge of the dead time or time constant, so we cannot judge the performance.

We note that the manipulated variable experiences very large (up to 10%) high frequency variation. This does not improve the CV performance, and it is fast enough to wear out the valve.

As a first step, we could filter the derivative mode (only). If this does not provide sufficient improvement, the derivative mode could be eliminated by setting the derivative time to zero.