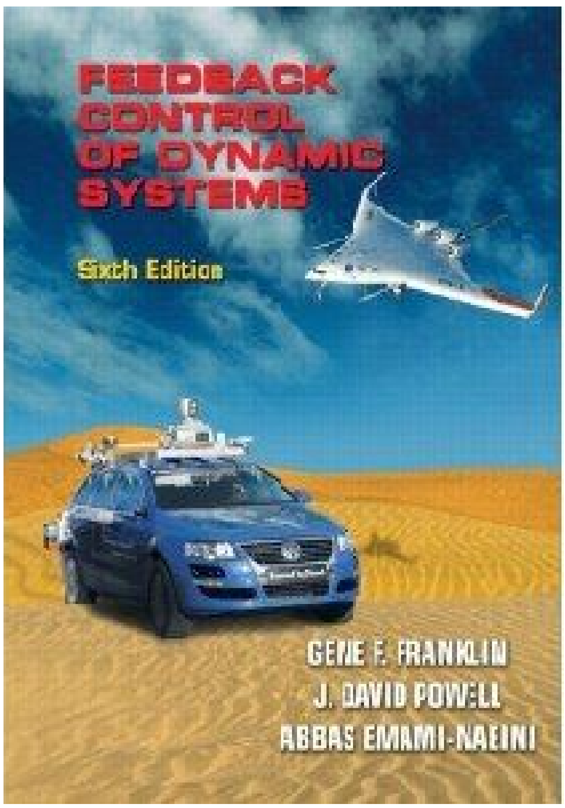
Solutions Manual

6th Edition

Feedback Control of Dynamic Systems



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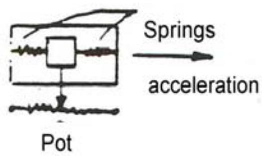
(i) Acceleration: A mass movement restrained by a spring measured by a potentiometer. A piezoelectric material may be used instead (a material that produces electrical current with intensity proportional to acceleration). In modern airbags, an integrated circuit chip contains a tiny lever and 'proof mass' whose motion is measured generating a voltage proportional to acceleration.



(j) Force, torque: A dynamometer based on spring or beam deflections, which may be measured by a potentiometer or a strain-gauge.

8. Each of the variables listed in Problem 7 can be brought under feedback control. Describe an actuator that could accept an electrical input and be used to control the variables listed. Give the units of the actuator output signal.

Solution:

(a) Resistor with voltage applied to it ormercury arc lamp to generate heat for small devices. a furnace for a building..

(b) Pump: Pumping air in or out of a chamberto generate pressure. Else, a 'torque motor' produces force..

(c) Valve and pump: forcing liquid in or out of the container.

(d) A valve is nromally used to control flow.

(e) Electric motor

(f) Electric motor

(g) Electric motor

(h) Electric motor

(i) Translational acceleration is usually controlled by a motor or engine to provide force on the vehicle or other object.

(j) Torque motor. In this motor the torque is directly proportional to the input (current).

which, with the square root approximations, is equivalent to,

$$\begin{aligned}
\delta\dot{h}_1 &= -\frac{1}{(30)}(1+\frac{1}{20}\delta h_1)+\frac{1}{(100)}W_{in} \\
\delta\dot{h}_2 &= \frac{1}{(30)}(1+\frac{1}{20}\delta h_1)-\frac{1}{(30)}(1+\frac{1}{20}\delta h_2)
\end{aligned}$$

The nominal inflow $W_{nom}=\frac{10}{3}$ cc/sec is required in order for the system to be in equilibrium, as can be seen from the first equation. So we will define the total inflow to be $W_{in}=W_{nom}+\delta W$, so the equations become

$$\begin{aligned}
\delta\dot{h}_1 &= -\frac{1}{(30)}(1+\frac{1}{20}\delta h_1)+\frac{1}{(100)}W_{nom}+\frac{1}{(100)}\delta W \\
\delta\dot{h}_2 &= \frac{1}{(30)}(1+\frac{1}{20}\delta h_1)-\frac{1}{(30)}(1+\frac{1}{20}\delta h_2)
\end{aligned}$$

or, with the nominal inflow included, the equations reduce to

$$\begin{aligned}
\delta\dot{h}_1 &= -\frac{1}{600}\delta h_1+\frac{1}{100}\delta W \\
\delta\dot{h}_2 &= \frac{1}{600}\delta h_1-\frac{1}{600}\delta h_2
\end{aligned}$$

Taking the Laplace transform of these two equations, and solving for the desired transfer function (in cc/sec) yields

$$\frac{\delta H_2(s)}{\delta W(s)}=\frac{1}{600}\frac{0.01}{(s+1/600)^2}.$$

which becomes, with the inflow in grams/min,

$$\frac{\delta H_2(s)}{\delta W(s)}=\frac{1}{600}\frac{(0.01)(60)}{(s+1/600)^2}=.\frac{0.001}{(s+1/600)^2}$$

(c) With hole B open and hole A closed, the relevant relations are

$$\begin{aligned}
W_{in}-W_B &= \rho A\dot{h}_1 \\
W_B &= \frac{1}{R}\sqrt{\rho g(h_1-h_2)} \\
W_B-W_C &= \rho A\dot{h}_2 \\
W_C &= \frac{1}{R}\sqrt{\rho g h_2}
\end{aligned}$$

$$\begin{aligned}
\dot{h}_1 &= -\frac{1}{\rho AR}\sqrt{\rho g(h_1-h_2)}+\frac{1}{\rho A}W_{in} \\
\dot{h}_2 &= \frac{1}{\rho AR}\sqrt{\rho g(h_1-h_2)}-\frac{1}{\rho AR}\sqrt{\rho g h_2}
\end{aligned}$$

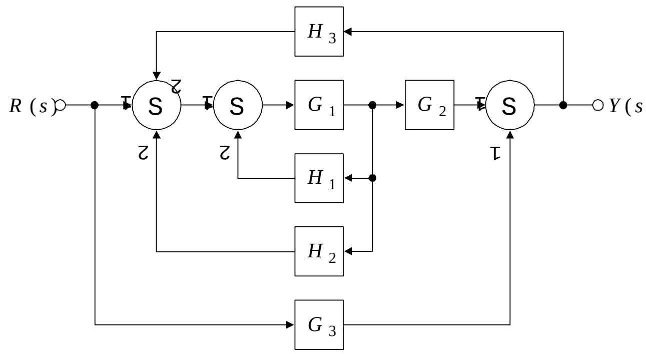
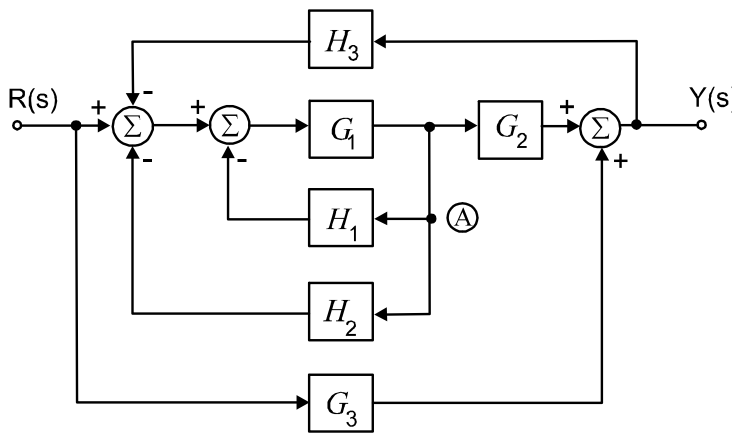
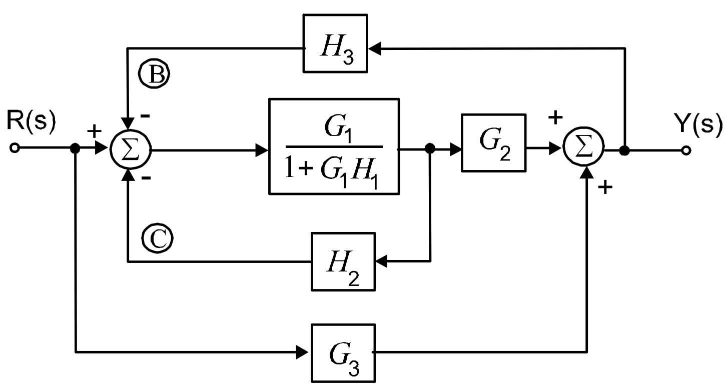


Figure 3.55: Block diagram for Problem 3.22

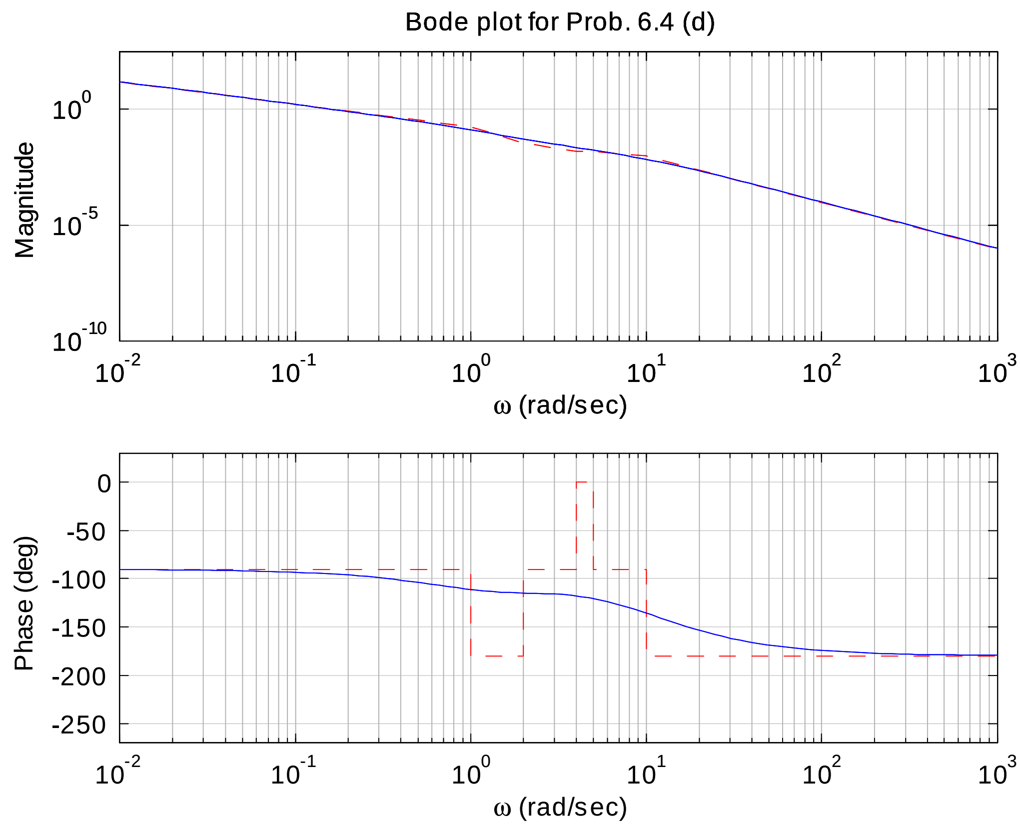


Block diagram for Fig. 3.55.

Move node A and close the loop:



Block diagram for Fig. 3.55: reduced.



5. *Complex poles and zeros* Sketch the asymptotes of the Bode plot magnitude and phase for each of the following open-loop transfer functions and approximate the transition at the second order break point based on the value of the damping ratio. After completing the hand sketches verify your result using MATLAB. Turn in your hand sketches and the MATLAB results on the same scales.

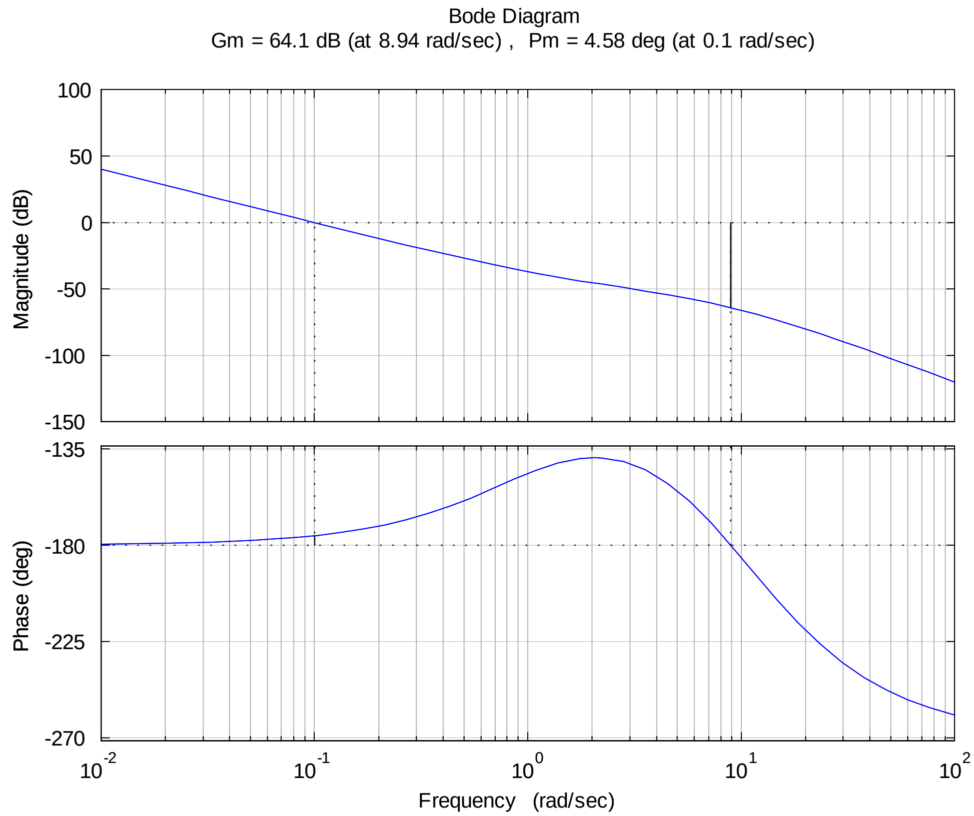
(a) $L(s) = \dfrac{1}{s^2 + 3s + 10}$

(b) $L(s) = \dfrac{1}{s(s^2 + 3s + 10)}$

(c) $L(s) = \dfrac{(s^2 + 2s + 8)}{s(s^2 + 2s + 10)}$

(d) $L(s) = \dfrac{(s^2 + 2s + 12)}{s(s^2 + 2s + 10)}$

(e) $L(s) = \dfrac{(s^2 + 1)}{s(s^2 + 4)}$



Since $GM = 64.1$ db ($\simeq 1600$), the range of K for stability is :

$$K < 1600$$

From the Bode plot, the magnitude at the frequency with $-150°$ phase is 0.0188 (-34.5 dB) at 0.8282 rad/sec and 0.00198 (-54.1 db) at 4.44 rad/sec. Therefore, the values of K at the points where $PM = 30°$ is :

$$\begin{aligned} K &= \frac{1}{0.0188} = 53.2, \\ K &= \frac{1}{0.00198} = 505 \end{aligned}$$

(b) For each of the equivalent digital systems in part (a), plot the Bode magnitude curves over the frequency range $\omega = 0.01$ to 10 rad/sec.

Solution:

(a) First, we'll compute the attenuation of the continuous system,

$$H(s) = \frac{10s+1}{100s+1}, \; |H(j\omega)|_{\omega=3} = 0.1001 \quad (-20 \text{ db})$$

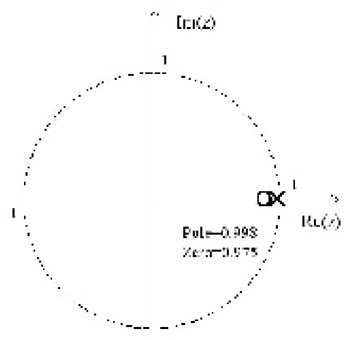
(1) Tustin's method :

$$\begin{aligned} H(z) &= H(s)|_{s=\frac{2}{T}\frac{1-z^{-1}}{1+z^{-1}}} = \frac{(20+T)+(T-20)z^{-1}}{(200+T)+(T-200)z^{-1}} \\ &= 0.10112\frac{z-0.97531}{z+0.99750} \end{aligned}$$

or, use c2d as shown for problem 5.
Gain attenuation at $\omega_1 = 3$: $|H(e^{j\omega_1 T})| = 0.1000$ $(-20$ db),
most easily computed from: [mag,phase]=bode(sysDTust,T,3).
(2) Matched pole-zero method :

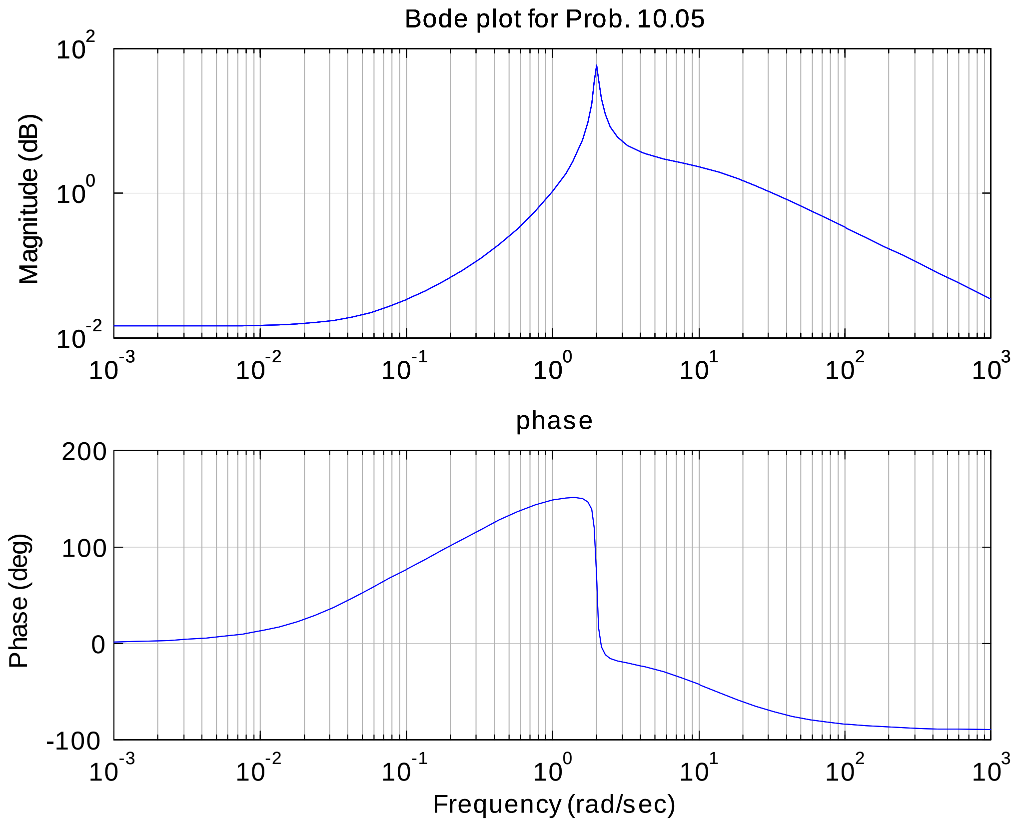
$$\begin{aligned} H(z) &= K\frac{z-e^{-0.1T}}{z-e^{-0.01T}} = 0.10113\frac{z-0.97531}{z-0.99750} \\ K &= 0.10113 \longleftarrow |H(z)|_{z=1} = |H(s)|_{s=0} \end{aligned}$$

Gain attenuation at $\omega_1 = 3$: $|H(e^{j\omega_1 T})| = 0.1001$ $(-20$ db),
most easily computed from: [mag,phase]=bode(sysDmpz,T,3).



In this case, the sampling rate is so fast compared to the break frequencies that both methods give essentially the same equivalent, and both have a gain attenuation of a factor of 10 at $\omega_1 = 3$ rad/sec.

(b) All three are essentially the same and indistinguishable on the plot because the range of interest is below the half sample fre-



Problem 10.5 PD control of an aircraft: Bode plot.