home / study / engineering / electrical engineering / control theory / control theory solutions manuals / feedback control of dynamic systems / 8th edition / chapter 6 / problem 7p

Feedback Control Of Dynamic Systems (8th Edition)

Chapter 6, Problem 7P

Step-by-step solution

Step 1 of 36

(a)

Consider the given open-loop transfer function.

$$L(s) = \frac{(s+2)}{s(s+10)(s^2+2s+2)}$$

Substitute $s = j\omega$.

$$L(j\omega) = \frac{(j\omega+2)}{j\omega(j\omega+10)(-\omega^2+2j\omega+2)} = \frac{(j\omega+2)}{j\omega(j\omega+10)\left((2-\omega^2)+2j\omega\right)}$$

Or,

$$L(j\omega) = \frac{0.1\left(\frac{j\omega}{2}+1\right)}{j\omega\left(\frac{j\omega}{10}+1\right)\left[-\left(\frac{\omega}{\sqrt{2}}\right)^2+j\omega+1\right]}$$

Thus, the break or corner frequencies for the given system are,

$\omega_1 = \sqrt{2}$ rad/sec

$\omega_2 = 2$ rad/sec

$\omega_3 = 10$ rad/sec

Comment

Step 2 of 36

Write the expression for the magnitude of the transfer function,

$$|L(j\omega)| = \left|\frac{(j\omega+2)}{j\omega(j\omega+10)\left((2-\omega^2)+2j\omega\right)}\right| = \left(\frac{\sqrt{(\omega^2+(2)^2)}}{\omega\sqrt{(\omega^2+(10)^2)}\left(\sqrt{\left((2-\omega^2)^2+(2\omega)^2\right)}\right)}\right)$$

Expression for the magnitude in terms of decibel dB is,

$$M = 20\log|L(j\omega)|$$

$$= 20\log\left(\frac{\sqrt{(\omega^2+(2)^2)}}{\omega\sqrt{(\omega^2+(10)^2)}\left(\sqrt{\left((2-\omega^2)^2+(2\omega)^2\right)}\right)}\right)$$

$$= 20\left[\log\left(\sqrt{(\omega^2+(2)^2)}\right)-\log\left(\omega\sqrt{(\omega^2+(10)^2)}\left(\sqrt{\left((2-\omega^2)^2+(2\omega)^2\right)}\right)\right)\right]$$

Comment

Follow the steps to draw the magnitude plot.

- The constant term '0.1' causes an increase in magnitude of $20 \log 0.1 = -20$ dB.
- The initial low frequency slope due to pole at the origin is -20dB/decade, and this slope intersects the 0dB line at $\omega = 1$ rad/sec
- At $\omega = \sqrt{2}$ rad/sec, the slope changes from -20dB /decade to -60dB /decade due to presence of $\left[-\left(\frac{\omega}{\sqrt{2}}\right)^2 + j\omega + 1\right]$ in the denominator. Since $2\xi\omega_n = 2$ and $\omega_n = \sqrt{2}$,

$\boxed{\therefore \xi = 0.707}$

- At $\omega = 2$ rad/sec, the slope changes from -60dB /decade to -40dB /decade due to presence of $\left(\frac{j\omega}{2} + 1\right)$ in the numerator.
- At $\omega = 10$ rad/sec, the slope changes from -40dB /decade to -60dB /decade due to the presence of $\left(\frac{j\omega}{10} + 1\right)$ in the denominator.

Comment

Step 4 of 36

Write the expression for the phase angle of the transfer function.

$$\begin{aligned}\phi(j\omega) &= \angle L(j\omega)\\ &= \angle\left(\frac{(j\omega+2)}{j\omega(j\omega+10)\left((2-\omega^2)+2j\omega\right)}\right)\\ &= -90^\circ + \tan^{-1}\left(\frac{\omega}{2}\right) - \tan^{-1}\left(\frac{\omega}{10}\right) - \tan^{-1}\left(\frac{2\omega}{(2-\omega^2)}\right)\end{aligned}$$

Comment

Step 5 of 36

Calculate the magnitude and phase angle for different values of ω as shown in Table 1.

Table 1

ω	M_{dB} (Magnitude in decible) $= 20\left[\log\left(\sqrt{(\omega^2+(2)^2)}\right) - \log\left(\omega\sqrt{(\omega^2+(10)^2)}\left(\sqrt{((2-\omega^2)^2+(2\omega)^2)}\right)\right)\right]$	$\phi(\omega)$ (Phase angle in degree) $= -90^\circ + \tan^{-1}\left(\frac{\omega}{2}\right) - \tan^{-1}\left(\frac{\omega}{10}\right) - \tan^{-1}\left(\frac{2\omega}{(2-\omega^2)}\right)$
0.01	20	-90.3438°
0.1	0.0103	-93.4496°
1	-20.0432	-132.58°
10	-62.841	-224.7753° (or, -44.7753°)
100	-120.041	-264.289° (or, -84.2892°)
1000	-180.0004	-269.4271° (or, -89.4271)

Comment

Step 6 of 36

Draw the Bode diagram as shown in Figure 1 using the above data.

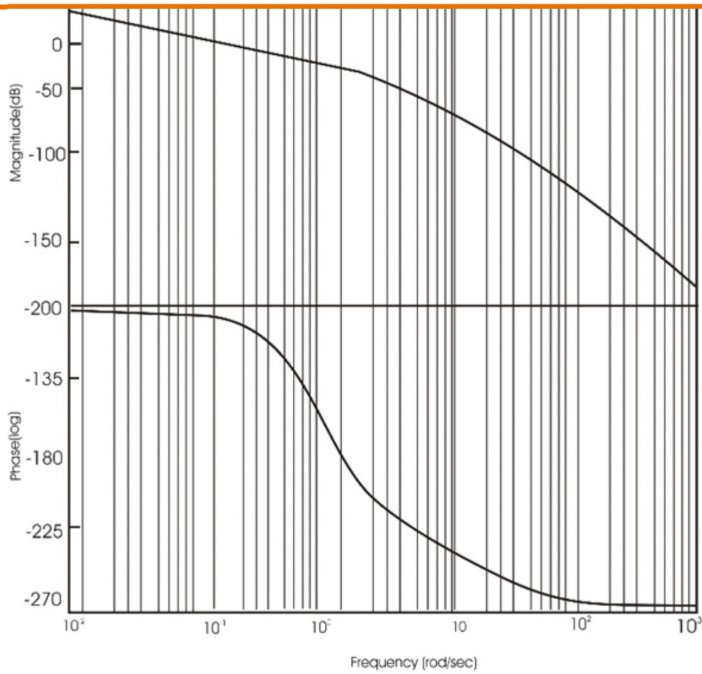

Figure 1

Comment

Step 7 of 36

Using MATLAB:

Consider the following MATLAB code to plot the bode diagram.

s=tf('s')sys=(s+2)/(s*(s+10)*(s^2+2*s+2))bode(sys)

Consider the MATLAB output as shown in Figure 1 (using MATLAB).

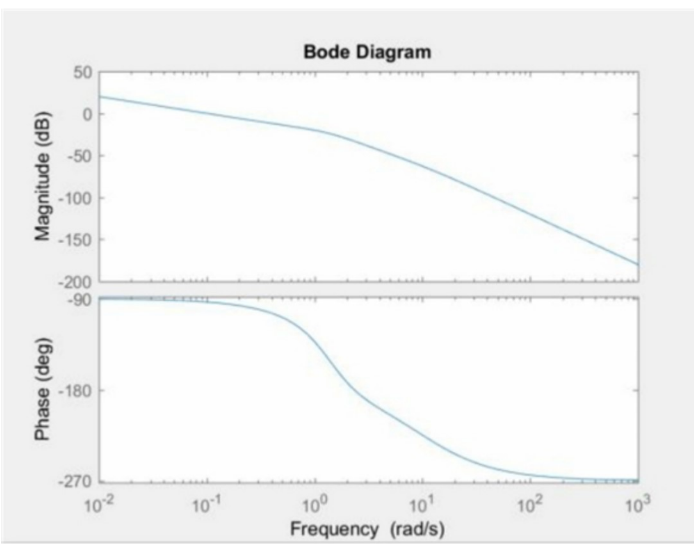

Figure 1(using MATLAB)

Comment

Step 8 of 36

$$L(s) = \frac{(s+2)}{s^2(s+10)(s^2+6s+25)}$$

Substitute $s = j\omega$.

$$L(j\omega) = \frac{(j\omega+2)}{-\omega^2(j\omega+10)(-\omega^2+6j\omega+25)}$$
$$= \frac{(j\omega+2)}{-\omega^2(j\omega+10)((25-\omega^2)+6j\omega)}$$

Or,

$$L(j\omega) = \frac{0.008\left(\frac{j\omega}{2}+1\right)}{-\omega^2\left(\frac{j\omega}{10}+1\right)\left[-\left(\frac{\omega}{5}\right)^2+0.24j\omega+1\right]}$$

Thus, the break or corner frequencies for the given system are,

$\omega_1 = 2$ rad/sec
$\omega_2 = 5$ rad/sec
$\omega_3 = 10$ rad/sec

Comment

Step 9 of 36

Write the expression for the magnitude of the transfer function,

$$|L(j\omega)| = \left|\frac{(j\omega+2)}{-\omega^2(j\omega+10)((25-\omega^2)+6j\omega)}\right|$$
$$= \left(\frac{\sqrt{(\omega^2+(2)^2)}}{\omega^2\sqrt{(\omega^2+(10)^2)}\left(\sqrt{((25-\omega^2)^2+(6\omega)^2)}\right)}\right)$$

Expression for the magnitude in terms of decibel dB is,

$$M = 20\log|L(j\omega)|$$
$$= 20\log\left(\frac{\sqrt{(\omega^2+(2)^2)}}{\omega^2\sqrt{(\omega^2+(10)^2)}\left(\sqrt{((25-\omega^2)^2+(6\omega)^2)}\right)}\right)$$
$$= 20\left[\log\left(\sqrt{(\omega^2+(2)^2)}\right)-\log\left(\omega^2\sqrt{(\omega^2+(10)^2)}\left(\sqrt{((25-\omega^2)^2+(6\omega)^2)}\right)\right)\right]$$

Comment

Step 10 of 36

• The initial low frequency slope due to the presence of two poles at the origin is -40 dB/ decade. And this asymptote intersects the 0dB line at $\omega = 1\text{rad/sec}$

• At $\omega = 2$ rad/sec, the slope changes from -40dB /decade to -20dB /decade due to presence of $\left(\frac{j\omega}{2}+1\right)$ in the numerator.

• At $\omega = 5$ rad/sec, the slope changes from -20dB /decade to -60dB /decade due to presence of $\left[-\left(\frac{\omega}{5}\right)^2+0.24j\omega+1\right]$ in the denominator.

Since $2\xi\omega_n = 6$ and $\omega_n=5$, therefore, $\boxed{\xi = 0.6}$

• At ω= 10 rad/sec, the slope changes from -60dB /decade to -80dB /decade due to the presence of $\left(\frac{j\omega}{10}+1\right)$ in the denominator.

Comment

Step 11 of 36

Write the expression for the phase angle of the transfer function.

$$\begin{aligned}\phi(j\omega) &= \angle L(j\omega)\\ &= \angle\left(\frac{(j\omega+2)}{-\omega^2(j\omega+10)\left((25-\omega^2)+6j\omega\right)}\right)\\ &= -180^\circ + \tan^{-1}\left(\frac{\omega}{2}\right) - \tan^{-1}\left(\frac{\omega}{10}\right) - \tan^{-1}\left(\frac{6\omega}{(25-\omega^2)}\right)\end{aligned}$$

Calculate the magnitude and phase angle for different values of ω as shown in Table 2.

Table 2

ω	M_{dB} (Magnitude in decible) $= 20\left[\log\left(\sqrt{(\omega^2+(2)^2)}\right) - \log\left(\omega^2\sqrt{(\omega^2+(10)^2)}\left(\sqrt{((25-\omega^2)^2+(6\omega)^2)}\right)\right)\right]$	$\phi(\omega)$ (Phase angle in degree) $= -180^\circ + \tan^{-1}\left(\frac{\omega}{2}\right) - \tan^{-1}\left(\frac{\omega}{10}\right) - \tan^{-1}\left(\frac{6\omega}{(25-\omega^2)}\right)$
0.1	−1.9268	−179.086°
1	−40.92	−222.58°
10	−82.489	−314.775° (or, −134.775°)
100	−160.035	−354.289° (or, −174.289°)
1000	−240.00035	−359.427° (or, −179.427°)

Comment

Step 12 of 36

Draw the Bode diagram as shown in Figure 2 using the above data.

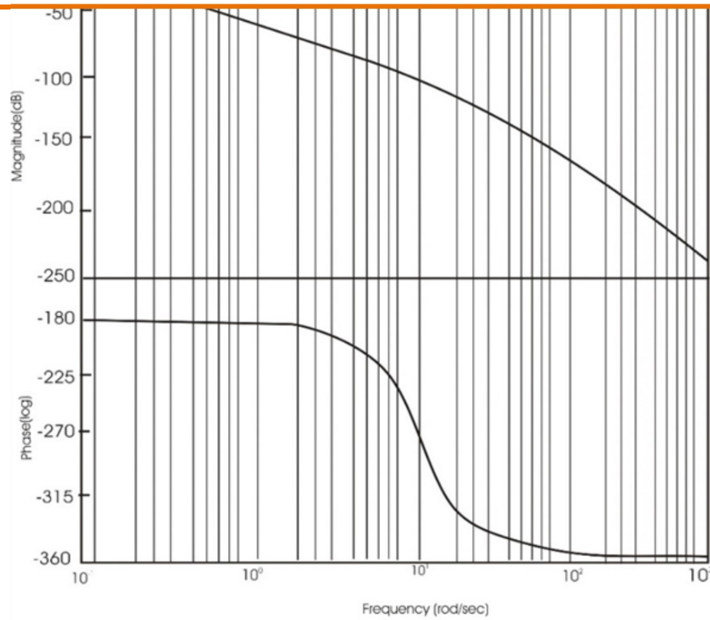

Figure 2

Comment

Step 13 of 36

Using MATLAB:

Consider the following MATLAB code to plot the bode diagram.

```
s=tf('s')sys=(s+2)/((s^2)*(s+10)*(s^2+6*s+25))bode(sys)
```

Comment

Step 14 of 36

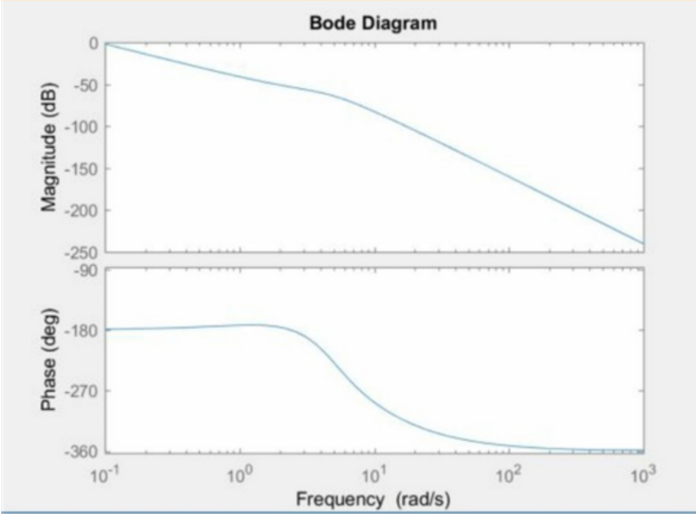

Figure 2 (using MATLAB)

Comment

Step 15 of 36

(c)

Consider the given open-loop transfer function.

$$L(s) = \frac{(s+2)^2}{s^2(s+10)(s^2+6s+25)}$$

Substitute $s = J\omega$.

$$L(j\omega) = \frac{\left(-\omega^2+4j\omega+4\right)}{-\omega^2\left(j\omega+10\right)\left(-\omega^2+6j\omega+25\right)}$$

$$= \frac{\left(4-\omega^2+4j\omega\right)}{-\omega^2\left(j\omega+10\right)\left(\left(25-\omega^2\right)+6j\omega\right)}$$

Or,

$$L(j\omega) = \frac{0.016\left[-\left(\frac{\omega}{2}\right)^2+j\omega+1\right]}{-\omega^2\left(\frac{j\omega}{10}+1\right)\left[-\left(\frac{\omega}{5}\right)^2+0.24j\omega+1\right]}$$

Thus, the break or corner frequencies for the given system are,

$\omega_1 = 2$ rad/sec
$\omega_2 = 5$ rad/sec
$\omega_3 = 10$ rad/sec

Comment

Step 16 of 36

Write the expression for the magnitude of the transfer function,

$$|L(j\omega)| = \left|\frac{\left(\left(4-\omega^2\right)+4j\omega\right)}{-\omega^2\left(j\omega+10\right)\left(\left(25-\omega^2\right)+6j\omega\right)}\right|$$

$$= \left(\frac{\sqrt{\left(\left(4-\omega^2\right)^2+\left(4\omega\right)^2\right)}}{\omega^2\sqrt{\left(\omega^2+\left(10\right)^2\right)}\left(\sqrt{\left(\left(25-\omega^2\right)^2+\left(6\omega\right)^2\right)}\right)}\right)$$

Expression for the magnitude in terms of decibel dB is,

$$= 20\log\left[\frac{\sqrt{(\ldots)}}{\omega^2\sqrt{\left(\omega^2+(10)^2\right)}\left(\sqrt{\left((25-\omega^2)^2+(6\omega)^2\right)}\right)}\right]$$

$$= 20\left[\log\left(\sqrt{\left((4-\omega^2)^2+(4\omega)^2\right)}\right)-\log\left(\omega^2\sqrt{\left(\omega^2+(10)^2\right)}\left(\sqrt{\left((25-\omega^2)^2+(6\omega)^2\right)}\right)\right)\right]$$

Comment

Step 17 of 36

Follow the steps to draw the magnitude plot.

• The constant term '0.016' causes an increase in magnitude of $20\log(0.016) = -36\text{ dB}$

• The initial low frequency slope due to the presence of two poles at the origin is -40dB/decade, and this asymptote intersects the 0dB line at $\omega = 1\text{rad/sec}$

• At $\omega = 2\text{ rad/sec}$, the slope changes from – 40dB/decade to 0dB/decade due to presence of $\left[-\left(\frac{\omega}{2}\right)^2 + j\omega + 1\right]$ in the numerator.

Since $2\xi\omega_n = 4$ and $\omega_n = 2$, Therefore $\boxed{\xi = 1}$

• At $\omega = 5$ rad/sec, the slope changes from 0dB /decade to -40dB /decade due to presence of $\left[-\left(\frac{\omega}{5}\right)^2 + 0.24 j\omega + 1\right]$ in the denominator.

Since $2\xi\omega_n = 6$ and $\omega_n = 5$, therefore $\boxed{\xi = 0.6}$.

• At $\omega = 10$ rad/sec, the slope changes from -60dB /decade to -80dB /decade due to the presence of $\left(\frac{j\omega}{10} + 1\right)$ in the denominator.

Comments (1)

Step 18 of 36

Write the expression for the phase angle of the transfer function.

$$\phi(j\omega) = \angle L(j\omega)$$

$$= \angle\left(\frac{\left((4-\omega^2)+4j\omega\right)}{-\omega^2(j\omega+10)\left((25-\omega^2)+6j\omega\right)}\right)$$

$$= -180° + \tan^{-1}\left(\frac{4\omega}{(4-\omega^2)}\right) - \tan^{-1}\left(\frac{\omega}{10}\right) - \tan^{-1}\left(\frac{6\omega}{(25-\omega^2)}\right)$$

Calculate the magnitude and phase angle for different values of ω as shown in Table 3.

Table 3

ω	M_{dB} (Magnitude in decible) $= 20\left[\log\left(\sqrt{\left((4-\omega^2)^2+(4\omega)^2\right)}\right) - \log\left(\omega^2\sqrt{\left(\omega^2+(10)^2\right)}\left(\sqrt{\left((25-\omega^2)^2+(6\omega)^2\right)}\right)\right)\right]$	$\phi(\omega)$ (Phase angle in degree) $= -180° + \tan^{-1}\left(\frac{4\omega}{(4-\omega^2)}\right) - \tan^{-1}\left(\frac{\omega}{10}\right) - \tan^{-1}\left(\frac{6\omega}{(25-\omega^2)}\right)$
0.1	4.1046	−176.224°
1	−33.93	−146.617°
10	−62.319	−208.96°
100	−120.0336	−263.139°
1000	−180.00038	−269.312°

Comment

Step 19 of 36

Draw the Bode diagram as shown in Figure 3 using the above data.

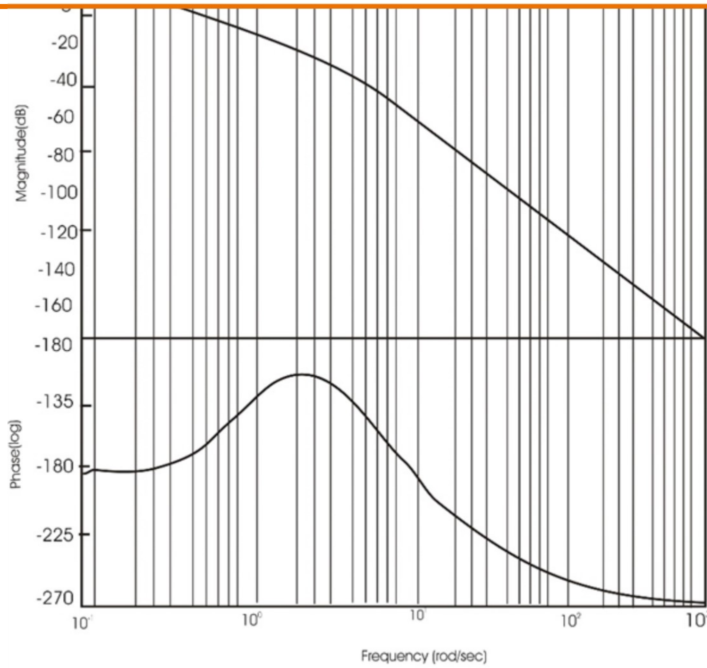

Figure 3

Comment

Step 20 of 36

Using MATLAB:

Consider the following MATLAB code to plot the bode diagram.

s=tf('s')sys=((s+2)^2)/((s^2)*(s+10)*(s^2+6*s+25))bode(sys)

Comment

Step 21 of 36

Consider the MATLAB output as shown in Figure 3 (using MATLAB).

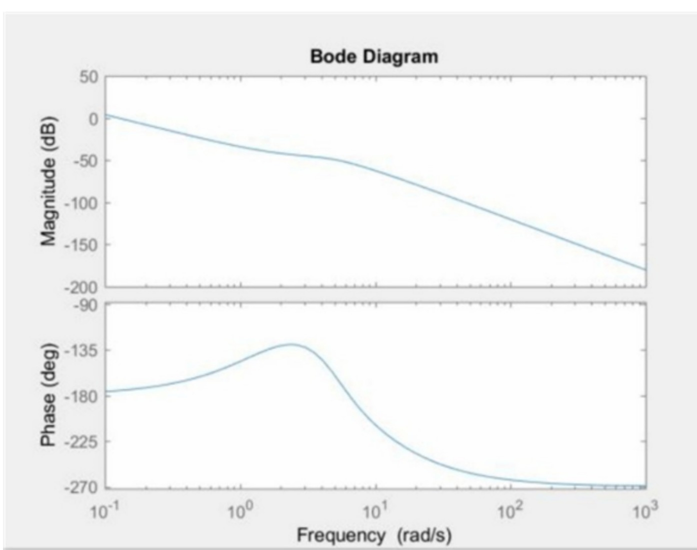

Figure 3 (using MATLAB)

Step 22 of 36

(d)

Consider the given open-loop transfer function.

$$L(s) = \frac{(s+2)(s^2+4s+68)}{s^2(s+10)(s^2+4s+85)}$$

Substitute $s = j\omega$.

$$L(j\omega) = \frac{(j\omega+2)(-\omega^2+4j\omega+68)}{-\omega^2(j\omega+10)(-\omega^2+4j\omega+85)}$$
$$= \frac{(j\omega+2)(68-\omega^2+4j\omega)}{-\omega^2(j\omega+10)(85-\omega^2+4j\omega)}$$

Or,

$$L(j\omega) = \frac{0.16\left(\frac{j\omega}{2}+1\right)\left[-\left(\frac{\omega}{8.24}\right)^2+0.06j\omega+1\right]}{-\omega^2\left(\frac{j\omega}{10}+1\right)\left[-\left(\frac{\omega}{9.22}\right)^2+0.05j\omega+1\right]}$$

Thus, the break or corner frequencies for the given system are,

$\omega_1 = 2$ rad/sec
ω_2=8.24 rad/sec
ω_3=9.22 rad/sec
ω_4=10 rad/sec

Comment

Step 23 of 36

Write the expression for the magnitude of the transfer function,

$$|L(j\omega)| = \left|\frac{(j\omega+2)((68-\omega^2)+4j\omega)}{-\omega^2(j\omega+10)((85-\omega^2)+4j\omega)}\right|$$
$$= \left(\frac{\left(\sqrt{(\omega^2+(2)^2)}\right)\left(\sqrt{((68-\omega^2)^2+(4\omega)^2)}\right)}{\omega^2\sqrt{(\omega^2+(10)^2)}\left(\sqrt{((85-\omega^2)^2+(4\omega)^2)}\right)}\right)$$

Expression for the magnitude in terms of decibel dB is,

$$M = 20\log|L(j\omega)|$$
$$= 20\log\left(\left(\frac{\left(\sqrt{\omega^2+(2)^2}\right)\left(\sqrt{(68-\omega^2)^2+(4\omega)^2}\right)}{\omega^2\sqrt{\omega^2+(10)^2}\left(\sqrt{(85-\omega^2)^2+(4\omega)^2}\right)}\right)\right)$$
$$= 20\left[\log\left(\sqrt{\omega^2+(2)^2}\right)\left(\sqrt{(68-\omega^2)^2+(4\omega)^2}\right)-\log\left(\omega^2\sqrt{\omega^2+(10)^2}\left(\sqrt{(85-\omega^2)^2+(4\omega)^2}\right)\right)\right]$$

Comment

Step 24 of 36

Follow the steps to draw the magnitude plot.

- The constant term '0.16' causes an increase in magnitude of 20 log 0.16= -16 dB.
- The initial low frequency slope due to the presence of two poles at the origin is -40dB/decade,and this assymptote intersects the 0dB line at ω = 1rad/sec
- At $\omega = 2$ rad/sec, the slope changes from -40dB /decade to -20dB /decade due to presence of $\left(\frac{J\omega}{2}+1\right)$ in the numerator.
- At $\omega = 8.24$ rad/sec, the slope changes from -20dB /decade to +20dB /decade

Since $2\xi\omega_n = 4$ and $\omega_n = 8.24$, therefore $\boxed{\xi = 0.243}$

- At $\omega = 9.22$ rad/sec, the slope changes from +20dB /decade to -20dB /decade due to presence of $\left[-\left(\frac{\omega}{9.22}\right)^2 + 0.05J\omega + 1\right]$ in the denominator.

Since $2\xi\omega_n = 4$ and $\omega_n = 9.22$, therefore $\boxed{\xi = 0.217}$

- At $\omega = 10$ rad/sec, the slope changes from -20dB /decade to -40dB /decade due to the presence of $\left(\frac{j\omega}{10}+1\right)$ in the denominator.

Comment

Step 25 of 36

Write the expression for the phase angle of the transfer function.

$$\phi(j\omega) = \angle L(j\omega)$$
$$= \angle\left(\frac{(j\omega+2)\left((68-\omega^2)+4j\omega\right)}{-\omega^2(j\omega+10)\left((85-\omega^2)+4j\omega\right)}\right)$$
$$= -180° + \tan^{-1}\left(\frac{\omega}{2}\right) + \tan^{-1}\left(\frac{4\omega}{(68-\omega^2)}\right) - \tan^{-1}\left(\frac{\omega}{10}\right) - \tan^{-1}\left(\frac{4\omega}{(85-\omega^2)}\right)$$

Comment

Step 26 of 36

Calculate the magnitude and phase angle for different values of ω as shown in Table 4.

Table 4

ω	M_{dB} (Magnitude in decible) $= 20\left[\log\left(\sqrt{\omega^2+(2)^2}\right)\left(\sqrt{(68-\omega^2)^2+(4\omega)^2}\right) - \log\left((\omega^2)\left(\sqrt{\omega^2+(10)^2}\right)\left(\sqrt{(85-\omega^2)^2+(4\omega)^2}\right)\right)\right]$	$\phi(\omega)$ (Phase angle in degree) $= -180° + \tan^{-1}\left(\frac{\omega}{2}\right) + \tan^{-1}\left(\frac{4\omega}{(68-\omega^2)}\right) - \tan^{-1}\left(\frac{\omega}{10}\right) - \tan^{-1}\left(\frac{4\omega}{(85-\omega^2)}\right)$
0.1	24.0926	−177.643°
1	−15.011	−158.455°
10	−41.26	−128.206°
100	−80.0266	−175.431°
1000	−120.00026	−179.542°

Comment

Step 27 of 36

Draw the Bode diagram as shown in Figure 4 using the above data.

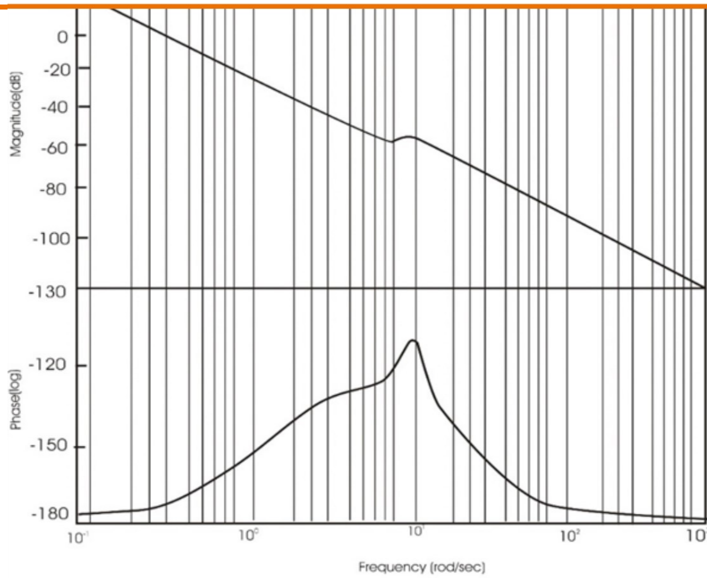

Figure 4

Comment

Step 28 of 36

Using MATLAB:

Consider the following MATLAB code to plot the bode diagram.

```
s=tf('s')sys=((s+2)*(s^2+4*s+68))/((s^2)*(s+10)*(s^2+4*s+85))bode(sys)
```

Consider the MATLAB output as shown in Figure 4 (using MATLAB).

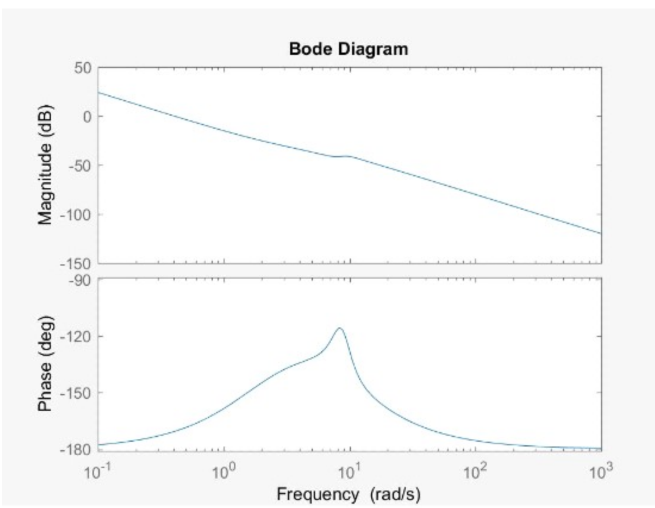

Figure 4(using MATLAB)

Comment

Step 29 of 36

(e)

Consider the given open-loop transfer function.

$$L(s) = \frac{(s^2+2s+2)}{s^2(s+2)(s+3)}$$

$$-\omega^2(j\omega+3)(j\omega+2)$$

$$=\frac{\left((2-\omega^2)+2j\omega\right)}{-\omega^2(j\omega+3)(j\omega+2)}$$

Or,

$$L(j\omega)=\frac{0.33\left[-\left(\frac{\omega}{\sqrt{2}}\right)^2+j\omega+1\right]}{-\omega^2\left(\frac{j\omega}{3}+1\right)\left(\frac{j\omega}{2}+1\right)}$$

Comment

Step 30 of 36

Thus, the break or corner frequencies for the given system are,

$\omega_1=\sqrt{2}$ rad/sec
ω_2=2 rad/sec
ω_3=3 rad/sec

Comment

Step 31 of 36

Write the expression for the magnitude of the transfer function,

$$|L(j\omega)|=\left|\frac{\left((2-\omega^2)+2j\omega\right)}{-\omega^2(j\omega+3)(j\omega+2)}\right|$$

$$=\left(\frac{\left(\sqrt{\left((2-\omega^2)^2+(2\omega)^2\right)}\right)}{\omega^2\sqrt{\left(\omega^2+(3)^2\right)}\left(\sqrt{\left(\omega^2+(2)^2\right)}\right)}\right)$$

Expression for the magnitude in terms of decibel dB is,

$$M=20\log|L(j\omega)|$$

$$=20\log\left(\left(\frac{\left(\sqrt{\left((2-\omega^2)^2+(2\omega)^2\right)}\right)}{\omega^2\sqrt{\left(\omega^2+(3)^2\right)}\left(\sqrt{\left(\omega^2+(2)^2\right)}\right)}\right)\right)$$

$$=20\left[\log\left(\sqrt{\left((2-\omega^2)^2+(2\omega)^2\right)}\right)-\log\left((\omega^2)\left(\sqrt{\left(\omega^2+(3)^2\right)}\right)\left(\sqrt{\left(\omega^2+(2)^2\right)}\right)\right)\right]$$

Comment

Step 32 of 36

Follow the steps to draw the magnitude plot.

- The constant term '0.33' causes an increase in magnitude of 20 log 0.33= -9.63 dB.
- The initial low frequency slope due to the prasence of two poles at the origin is -40dB/decade, and this slope intersects the 0dB line at ω = 1rad/sec
- At $\omega=\sqrt{2}$ rad/sec, the slope changes from -40dB /decade to 0dB /decade due to presence of $\left[-\left(\frac{\omega}{\sqrt{2}}\right)^2+j\omega+1\right]$ in the numerator. Since $2\xi\omega_n=2$ and $\omega_n=\sqrt{2}$, therefore $\boxed{\xi=0.707}$
- At $\omega=2$ rad/sec, the slope changes from 0 dB/decade to -20 dB/decade due to the presence of $\left(\frac{j\omega}{2}+1\right)$ in the denominator.
- At $\omega=3$ rad/sec, the slope changes from -20 dB/decade to -40 dB/decade

Comment

Step 33 of 36

Write the expression for the phase angle of the transfer function.

$$\phi(j\omega) = \angle L(j\omega)$$
$$= \angle\left(\frac{\left((2-\omega^2)+2j\omega\right)}{-\omega^2(j\omega+3)(j\omega+2)}\right)$$
$$= -180^\circ + \tan^{-1}\left(\frac{2\omega}{(2-\omega^2)}\right) - \tan^{-1}\left(\frac{\omega}{3}\right) - \tan^{-1}\left(\frac{\omega}{2}\right)$$

Calculate the magnitude and phase angle for different values of ω as shown in Table 5.

Table 5

ω	M_{dB} (Magnitude in decible) $= 20\left[\log\left(\sqrt{\left((2-\omega^2)^2+(2\omega)^2\right)}\right) - \log\left((\omega^2)\left(\sqrt{(\omega^2+(3)^2)}\right)\left(\sqrt{(\omega^2+(2)^2)}\right)\right)\right]$	$\phi(\omega)$ (Phase angle in degree) $= -180^\circ + \tan^{-1}\left(\frac{2\omega}{(2-\omega^2)}\right) - \tan^{-1}\left(\frac{\omega}{3}\right) - \tan^{-1}\left(\frac{\omega}{2}\right)$
0.1	30.4420	-179.032°
1	-10	-161.56°
10	-54.513	-163.525° (or, -343.525°)
100	-80.0056	-178.282° (or, -358.282°)
1000	-120.00	-179.828° (or, -359.828°)

Comment

Step 34 of 36

Draw the Bode diagram as shown in Figure 5 using the above data.

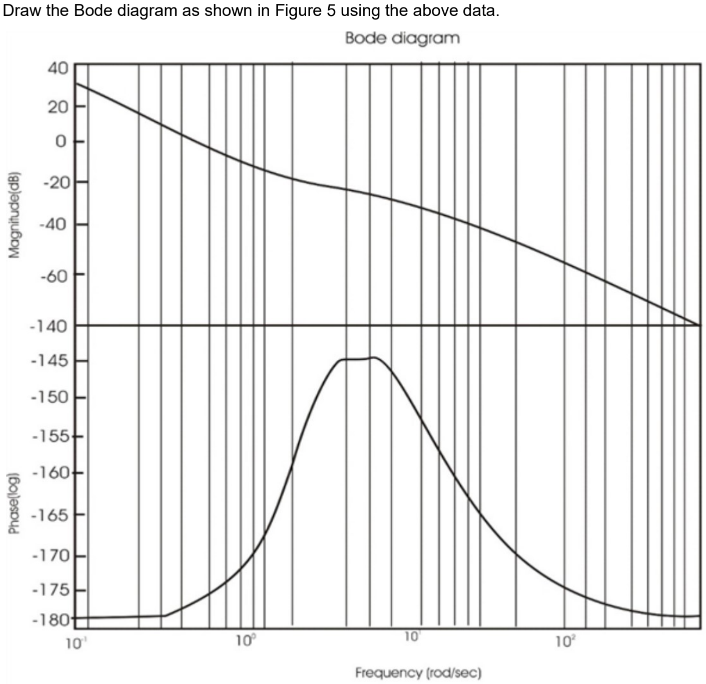

Figure 5

Comment

Using MATLAB:

Consider the following MATLAB code to plot the bode diagram.

```
s=tf('s')sys=((s+1)^2+1)/ ((s^2) *(s+2)*(s+3)) bode(sys)
```

Comment

Step 36 of 36

Consider the MATLAB output as shown in Figure 5 (using MATLAB).

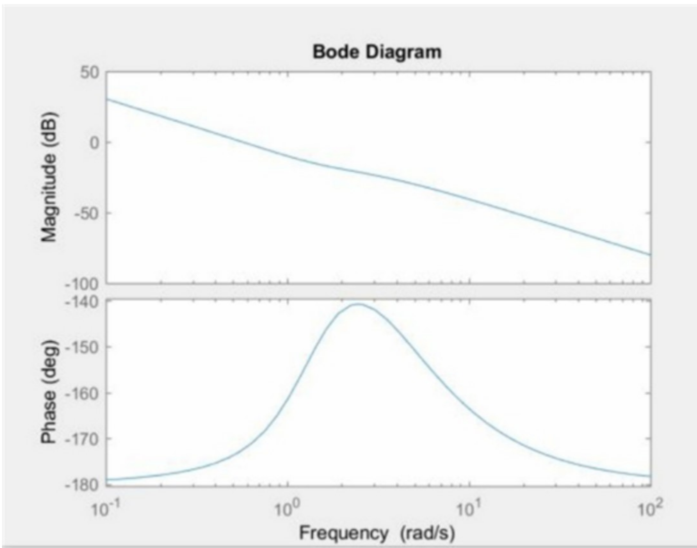

Figure 5 (using MATLAB)

Therefore, the bode diagram is verified using the MATLAB as shown in the above diagram.

Comment

Was this solution helpful? 1 0

Recommended solutions for you in Chapter 6