1) \( g(s) = \frac{5}{5 (1.641 + 1)(1.65 + 1)} \)

Keep DC gain constant

\[-140 = -90 - \tan^{-1}(\frac{4}{1.641}) - \tan^{-1}(\frac{4}{1.65}) + \sin^{-1}(\frac{0.5}{0.651})\]

\( \alpha \) has max value of 10 to keep noise rejection reasonable.

\[-140 = -90 - \tan^{-1}(\frac{4}{1.641}) - \tan^{-1}(\frac{4}{1.65}) + 53.0\]

\( \omega_c = 2.7 \quad \text{max crossover} \)

Need geometric mean of lead to be equal to \( \omega_c \).

\( \omega_c = \frac{1}{\alpha z} \quad \alpha = \frac{1}{1.164} \quad z = 0.1164 \)

\[ l = K \left( \frac{10 \cdot 0.11641 \cdot 2.73 + 1}{0.11641 \cdot 2.73^2 + 1} \right)^{\frac{1}{2}} \cdot \frac{5}{2.7 \left( \frac{2.7}{2.7} + 1 \right)^{\frac{1}{2}} \left( \frac{0.3}{0.3} + 1 \right)^{\frac{1}{2}}} \]

\[ l = 3.14633 \quad \alpha = 0.633615 \]

\( K = 0.5 \)

\( \text{lead} = \frac{1}{2} \left( \frac{10 \cdot 0.11641 z + 1}{0.11641 z^2 + 1} \right) \)
1. \( \Phi_\ell = \frac{3}{\left( \frac{3}{1} + 1 \right) \left( \frac{3}{6} + 1 \right)} \)

\[
\theta = \frac{\sqrt{x+1}}{\sqrt{y+1}}
\]

\( \Phi_\ell = \frac{3}{x+1} \quad \Phi_\ell = 100 \) gives \( \Phi = 0^\circ \) of phase

Placing zero at current crossover will keep crossover somewhat the same. However, the additional increase in gain due to lead, will increase we slightly, and the phase margin becomes negative. To compensate, we need a large \( \Phi_\ell \) to make up for that lost phase and push up to a 40° phase margin. Thus, choose \( \Phi_\ell = x \), placing zero at crossover, \( \omega_c \).

The plant phase rolls off quicker than the phase lead compensation gives you. So you want to push crossover as little as possible. Therefore, you want \( \omega_c \) to occur early in the lead compensator.

This will reduce the bad effect of the system phase at higher frequencies.

6: \( \theta = \frac{\sqrt{x+1}}{\sqrt{2y+1}} \) Try this compensator and iterate if necessary

check bode plots -- Approx. bandwidth is open loop \( \omega_c \)
There are MANY answers! \( \omega_c = 2,3076 \)
Bode Diagrams

$G_m = 33.295 \text{ dB (at } 21.884 \text{ rad/sec)}, \quad P_m = 37.132 \text{ deg. (at } 2.8076 \text{ rad/sec)}$
2) \( \frac{h(s)}{e(s)} = \frac{15(s+0.01)}{s^2 + 0.01s + 0.0025} \)

b) \( \left| \frac{h(s)}{e(s)} \right| = 1 = K \frac{60 \left( \frac{0.16}{0.01} \right)^2 \left(\frac{1}{1+0.0025\frac{s}{0.01}} \right)^{1/2}}{0.16 \left( \frac{0.16}{0.0025} + (1-\frac{0.16}{0.0025}) \right)^{1/2}} \)

\[ K = \frac{1}{0.01} = 100 \]

\[ K = 0.0015 \]

c) \( Y_{\omega} \), the phase never goes below -180°

d) \( x(s) = -90 - \tan^{-1}\left(\frac{0.16}{0.01}\right) - \tan^{-1}\left(\frac{0.16}{0.0025\cdot 1.6^2}\right) = -178.615 \)

\[ \theta_m = 0.385 \]

e) \( 1 + K(s) = (s^2 + 0.16s + 0.0025)s + K(15)(s + 0.01) = 0 \)

\[ K = 0.0015 \]

Solve system for \( s \)

Poles at \( s = -0.009 \), \( \omega_m = 0.158 \)
9.) \( \frac{\varepsilon(5)}{E(5)} = \frac{1}{1 + 46} = \frac{1}{51} = \frac{5}{51} \left( \frac{3^2 + 0.15 + 0.0525}{3^2 + 0.15 + 0.0525} \right) \)

\( \varepsilon_5 = \frac{1}{570} \left( \frac{5 \varepsilon(5)}{3^2 + 0.15 + 0.0525} \right) \)

\( \varepsilon_5 = \frac{0.0025}{15 \times 10^3} = \frac{1}{60} \times 10^{-3} = 11.1 = \varepsilon_5 \)
w) 
\[ H(s) = K \frac{s^2 + 2s + 1}{s^2 + 1} \]

Write \( H(s) = K' \frac{\alpha T s + 1}{T s + 1} \) because \( \phi_H = \sin^{-1} \left( \frac{\alpha}{\alpha + 1} \right) \) and \( \omega_c = \frac{1}{\sqrt{\alpha T}} \).

\[ \phi_H (\omega = 0.16) = \tan^{-1} \left( \frac{0.16}{0.01} \right) = 90^\circ - \tan^{-1} \left( \frac{0.16}{0.005} \right) - \tan^{-1} \left( \frac{0.16}{0.005} \right) = -179.6^\circ \]

Choose \( \alpha = 10 \) so that \( \phi_H \approx 55^\circ \).

\[ T = \frac{1}{4\omega_c \omega_e} = 1.98 \]

\[ a = \frac{1}{\alpha T} = 0.05 \]

\[ b = \frac{1}{T} = 0.5 \]

Need \( K \left| \frac{(s/0.05 + 1)}{1} \right| \left| G(s) \right| = 1 \) at \( \omega_c = 0.16 \) \( \Rightarrow K = 4.83 \times 10^{-2} \).

Result is \( PM = 55.3^\circ \) at \( \omega_c = 0.16 \).

Other solutions are possible.

---

1.

CL poles for \( K \) from part (k):

- \( 0.05 \pm 0.083 \)
j) for type 1 system

es for a ramp input = \frac{1}{K_{b0c}} = \frac{1}{60(4.82 \times 10^{-4})} = 34.5

k) Need to increase the type of the system to type 2 to

make error go to zero.

- Add integrator, \frac{1}{s}

However, the integrator will give too much negative phase.

- Add low frequency zero at least 1 decade before \omega_c

\omega_c > \frac{1}{0.016}

Compensation of form

\begin{pmatrix}
K \frac{1}{s+1} \\
\leq
\end{pmatrix}