Figure 10.38
Second-order closed-loop system

\[ R(s) + \frac{\omega_n^2}{s(s + 2\zeta\omega_n)} \rightarrow C(s) \]
Figure 10.39
Representative log-magnitude plot of 2\textsuperscript{nd} Order System
Figure 10.40
Closed-loop frequency percent overshoot for a two-pole system
Figure 10.41
Normalized bandwidth vs. damping ratio for:
(a) settling time;
(b) peak time;
(c) rise time
Figure 10.48
Phase margin vs. damping ratio
Figure 10.49
Open-loop gain vs. open-loop phase angle for −3 dB closed-loop gain

Closed-loop magnitude = −3 dB
## Table 7.2
Relationships between input, system type, static error constants, and steady-state errors

<table>
<thead>
<tr>
<th>Input</th>
<th>Steady-state error formula</th>
<th>Type 0</th>
<th>Type 1</th>
<th>Type 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Static error constant</td>
<td>Error</td>
<td>Static error constant</td>
</tr>
<tr>
<td>Step, $u(t)$</td>
<td>$\frac{1}{1 + K_p}$</td>
<td>$K_p = \text{Constant}$</td>
<td>$\frac{1}{1 + K_p}$</td>
<td>$K_p = \infty$</td>
</tr>
<tr>
<td>Ramp, $tu(t)$</td>
<td>$\frac{1}{K_v}$</td>
<td>$K_v = 0$</td>
<td>$\infty$</td>
<td>$K_v = \text{Constant}$</td>
</tr>
<tr>
<td>Parabola, $\frac{1}{2}t^2u(t)$</td>
<td>$\frac{1}{K_a}$</td>
<td>$K_a = 0$</td>
<td>$\infty$</td>
<td>$K_a = \text{Constant}$</td>
</tr>
</tbody>
</table>
Figure 10.52
Bode log-magnitude plots for Example 10.14

Type 0
Slope=0 db/dc

Type 1
Slope=-20 db/dc

Type 2
Slope=-40 db/dc
Step 1: Bode plot, any $K$

Step 2: Required Phase Margin

Step 3: CD $\rightarrow$ Desired Phase Margin $\rightarrow$ frequency at which to change 0 dB crossover

Step 4: AB $\rightarrow$ $K$ needed to adjust phase margin

Bode plots showing gain adjustment for a desired phase margin
System for Example 11.1

Desired position $R(s)$

Preamplifier

Power amplifier

Motor and load

Shaft velocity

Shaft position $C(s)$
Bode magnitude and phase plots for Example 11.1

Magnitude before gain adjustment

Magnitude after gain adjustment

New Phase Margin
Characteristics of gain-compensated system of Example 11.1

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Proposed Specification</th>
<th>Actual Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K_v$</td>
<td>—</td>
<td>16.22</td>
</tr>
<tr>
<td>Phase margin</td>
<td>59.2°</td>
<td>59.2°</td>
</tr>
<tr>
<td>Phase-margin frequency</td>
<td>—</td>
<td>14.8 rad/s</td>
</tr>
<tr>
<td>Percent overshoot</td>
<td>9.5</td>
<td>10</td>
</tr>
<tr>
<td>Peak time</td>
<td>—</td>
<td>0.18 second</td>
</tr>
</tbody>
</table>
**Step 1:** Bode plot, $K$ satisfies steady-state error specification

**Step 2:** Frequency at which Phase = (5 to 10deg) + (Required Phase Margin)

**Step 3:** Select Lag Compensator to cause 0db crossing to be at frequency in Step 2

**Step 4:** Reset $K$ to compensate for lag network to keep static error constant the same as in Step 1
Figure 11.5 Frequency response plots of a lag compensator, $G_c(s) = (s + 0.1)/(s + 0.01)$
Figure 11.6 Bode plots for Example 11.2
## Table 11.2
Characteristics of the lag-compensated system of Example 11.2

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Proposed Specification</th>
<th>Actual Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K_v$</td>
<td>162.2</td>
<td>161.5</td>
</tr>
<tr>
<td>Phase margin</td>
<td>59.2°</td>
<td>62°</td>
</tr>
<tr>
<td>Phase-margin frequency</td>
<td>—</td>
<td>11 rad/s</td>
</tr>
<tr>
<td>Percent overshoot</td>
<td>9.5</td>
<td>10</td>
</tr>
<tr>
<td>Peak time</td>
<td>—</td>
<td>0.25 second</td>
</tr>
</tbody>
</table>
Figure 11-7
Visualizing lead compensation
Figure 11.8 Frequency response of a lead compensator

\[ G_c(s) = \left[ \frac{1}{\beta} \right] \frac{(s + \frac{1}{T})}{(s + \frac{1}{\beta T})} \]
Figure 11-9  Bode plots for lead compensation in Example 11.3