$$G(s)H(s)=\frac{1}{(1+0.5s)(1+2s)}$$

$$G(j\omega)H(j\omega)=\frac{1}{(1+\frac{j\omega}{2})(1+\frac{j\omega}{0.5})}$$

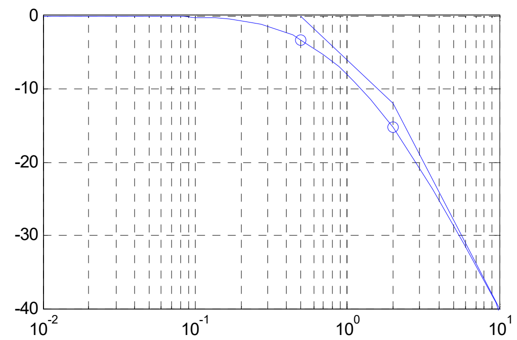
$$\omega_1=0.5rad/\sec \quad L_{0.5}=-20\log\sqrt{1+\left(\frac{\omega}{0.5}\right)^2}$$

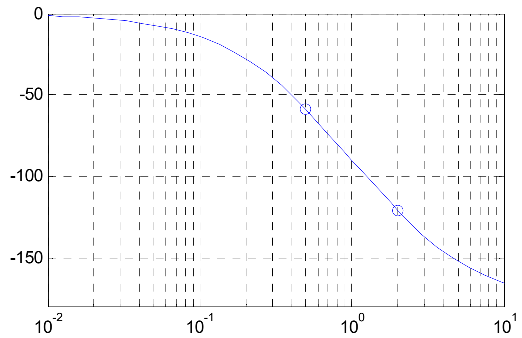
$$\omega_2=2rad/\sec \quad L_2=-20\log\sqrt{1+\left(\frac{\omega}{2}\right)^2}$$

	0.5	2
L0.5	-3.0103	-12.3045
L2	-0.2633	-3.0103
dB	-3.2736	-15.3148

$$\varphi(\omega)=-tg^{-1}\left(\frac{\omega}{0.5}\right)-tg^{-1}\left(\frac{\omega}{2}\right)$$

0.1	0.2	0.5	1	2	5
-14.17	-27.51	-59.04	-90	-120.96	-152.49





$$G(s)H(s)=\frac{(1+0.5s)}{s^2}$$

$$G(j\omega)H(j\omega)=\frac{(1+\frac{j\omega}{2})}{j\omega^2}$$

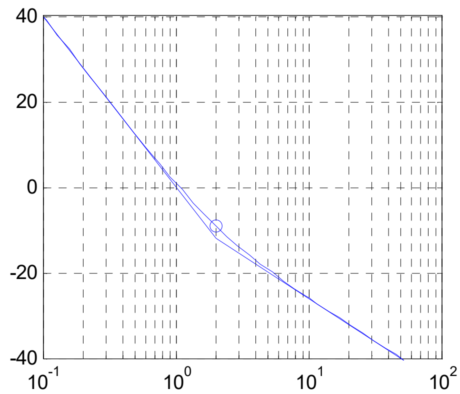
$$\omega_1=2rad/\sec \quad L_2=-20\log\sqrt{1+\left(\frac{\omega}{2}\right)^2}$$

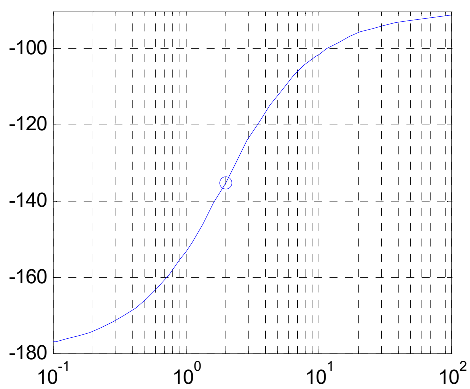
$$L_I=-20\log\omega \quad L_I=-20\log\omega$$

	2
L2	3.0103
LI	-6.02
LI	-6.02
dB	9.03

$$\varphi(\omega)=tg^{-1}\left(\frac{\omega}{2}\right)-90-90$$

2
-135





$$G(s)H(s)=\frac{s+10}{s^2+6s+10}$$

$$G(j\omega)H(j\omega)=\frac{(1+\frac{j\omega}{10})}{\left(1-\left(\frac{\omega}{\sqrt{10}}\right)^2\right)+\frac{j6\omega}{10}}$$

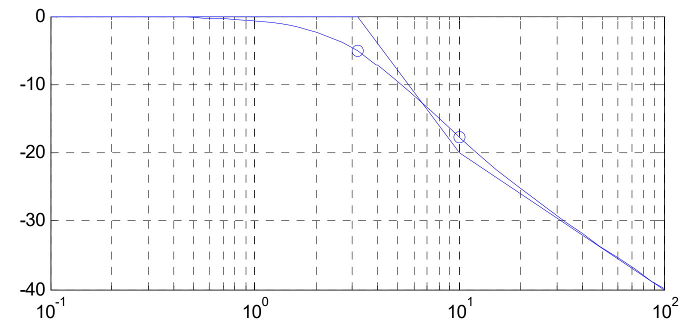
$$\omega_1=10rad/\sec \quad L_{10}=20\log\sqrt{1+\left(\frac{\omega}{10}\right)^2}$$

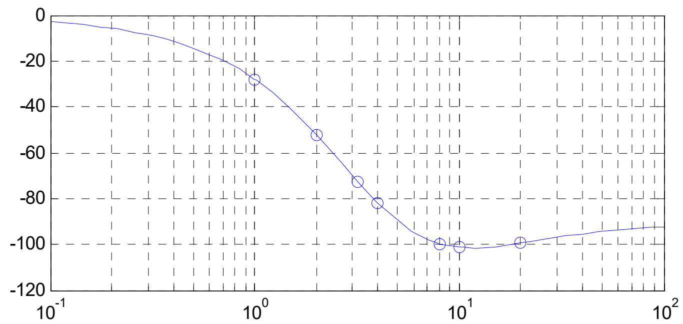
$$\omega_2=\sqrt{10}rad/\sec \quad \zeta=\frac{3}{\sqrt{10}}$$

$$L_2=-20\log\sqrt{\left[1-\left(\frac{\omega}{\sqrt{10}}\right)^2\right]^2+\left(\frac{6\omega}{10}\right)^2}$$

	2	3.1623	4	10
$L_{3.1623}$	-2.5527	-5.563	-7.8675	-20.682
L_{10}	0.1703	0.4139	0.6446	3.0103
dB	-2.3824	-5.1491	-7.2229	-17.672

$\omega<\sqrt{10}$	$\varphi(\omega)=tg^{-1}0.1\omega-tg^{-1}\frac{6\omega/10}{1-\omega^2/10}$						
ω	0.2	0.5	1	2	3	3.1623	
$\varphi(\omega)$	-5.72	-14.24	-27.98	-52.13	-70.12	-72.45	
$\omega>\sqrt{10}$	$\varphi(\omega)=tg^{-1}0.1\omega-180°+tg^{-1}\frac{6\omega/10}{1-\omega^2/10}$						
ω	4	5	10	20	30	50	100
$\varphi(\omega)$	-82.23	-90	-101.3	-99.46	-97	-94.44	-92.27





$$G(s)H(s)=\frac{30(s+8)}{s(s+2)(s+4)}$$

$$G(j\omega)H(j\omega)=\frac{30(j\frac{\omega}{8}+1)}{j\omega(j\frac{\omega}{2}+1)(j\frac{\omega}{4}+1)}$$

$$\omega_1=2rad/\sec \quad L_2=-20\log\sqrt{1+\left(\frac{\omega}{2}\right)^2}$$

$$\omega_2=4rad/\sec \quad L_4=-20\log\sqrt{1+\left(\frac{\omega}{4}\right)^2}$$

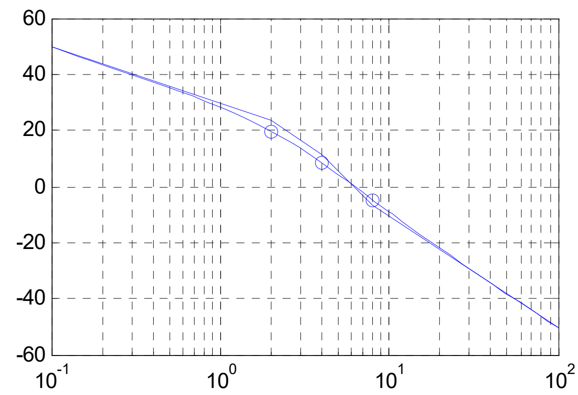
$$\omega_3=8rad/\sec \quad L_8=20\log\sqrt{1+\left(\frac{\omega}{8}\right)^2}$$

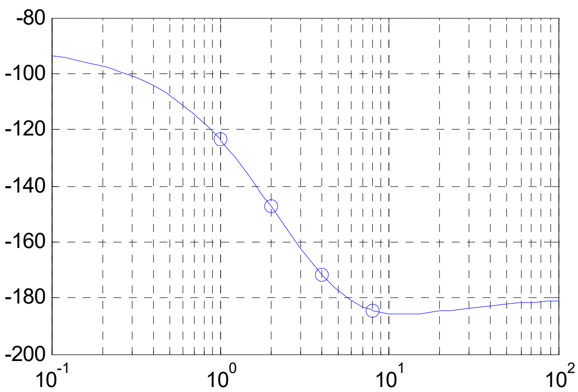
积分环节 $L_I=20\log\omega$

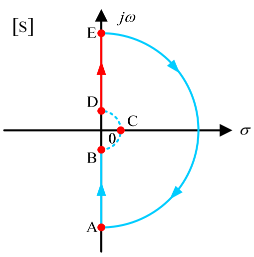
	2	4	8
L2	-3.01	-6.99	-12.3
L4	-0.97	-3.01	-6.99
L8	0.26	0.97	3.01
LI	-6.02	-12.04	-18.06
	-9.74	-21.07	-34.34
LK	29.54	29.54	29.54
	19.80	8.47	-4.8

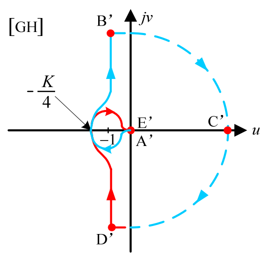
$$\varphi(\omega)=tg^{-1}\left(\frac{\omega}{8}\right)-tg^{-1}\left(\frac{\omega}{4}\right)-tg^{-1}\left(\frac{\omega}{2}\right)-90^\circ$$

	$\varphi(\omega)=tg^{-1}\left(\frac{\omega}{8}\right)-tg^{-1}\left(\frac{\omega}{4}\right)-tg^{-1}\left(\frac{\omega}{2}\right)-90^\circ$									
ω	0.2	0.5	1	2	5	8	10	20	50	100
$\varphi(\omega)$	-97.1409	-107.58	-123.48	-147.53	-177.53	-184.4	-185.55	-184.78	-182.23	-181.14

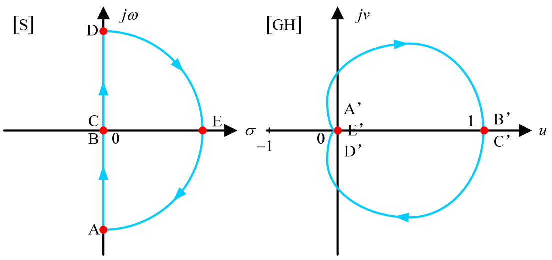
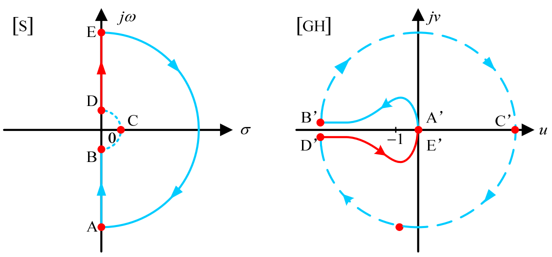
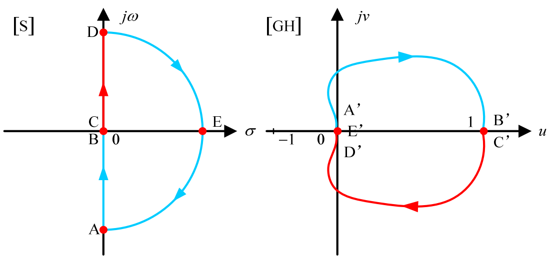
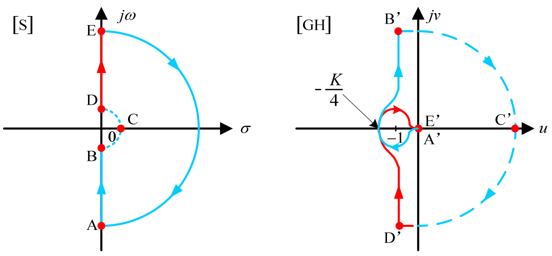








习题 2

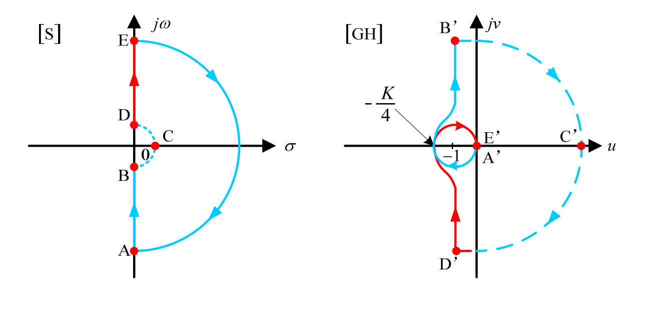
 P=0 N=0 Z=N+P=0 系统稳定	$A: s=\infty e^{-j90^\circ}$ $A': G(s)H(s)=\dfrac{K}{s^2}=\dfrac{K}{\infty e^{-j90^\circ\times 2}}=0e^{j180^\circ}$ $B: s=0e^{-j90^\circ}$ $B': G(s)H(s)=e^{j0^\circ}$ $C: s=0e^{j90^\circ}$ $C': G(s)H(s)=e^{j0^\circ}$ $D: s=\infty e^{j90^\circ}$ $D': G(s)H(s)=0e^{-j180^\circ}$ $E: s=\infty e^{j0^\circ}$ $E': G(s)H(s)=0e^{j0^\circ}$
 P=0 N=0 Z=N+P=0 系统稳定	$A: s=\infty e^{-j90^\circ}$ $A': G(s)H(s)=\dfrac{0.5}{s}=\dfrac{0.5}{\infty e^{-j90^\circ}}=0e^{j90^\circ}$ $B: s=\varepsilon e^{-j90^\circ}$ $B': G(s)H(s)=\dfrac{1}{s^2}=\infty e^{j180^\circ}$ $C: s=\varepsilon e^{j0^\circ}$ $C': G(s)H(s)=\infty e^{j0^\circ}$ $D: s=\varepsilon e^{j90^\circ}$ $D': G(s)H(s)=\infty e^{-j180^\circ}$ $E: s=\infty e^{j90^\circ}$ $E': G(s)H(s)=0e^{-j90^\circ}$
 P=0 N=0 Z=N+P=0 系统稳定	$A: s=\infty e^{-j90^\circ}$ $A': G(s)H(s)=\dfrac{1}{s}=\dfrac{1}{\infty e^{-j90^\circ}}=0e^{j90^\circ}$ $B: s=0e^{-j90^\circ}$ $B': G(s)H(s)=1$ $C: s=0e^{j90^\circ}$ $C': G(s)H(s)=1$ $D: s=\infty e^{j90^\circ}$ $D': G(s)H(s)=0e^{-j90^\circ}$ $E: s=\infty e^{j0^\circ}$ $E': G(s)H(s)=0e^{j0^\circ}$
 P=0 N=2 Z=N+P=2 系统不稳定	$A: s=\infty e^{-j90^\circ}$ $A': G(s)H(s)=\dfrac{30}{s^2}=\dfrac{30}{\infty e^{-j2\times 90^\circ}}=0e^{j180^\circ}$ $B: s=\varepsilon e^{-j90^\circ}$ $B': G(s)H(s)=\dfrac{1}{s}=\infty e^{j90^\circ}$ $C: s=\varepsilon e^{j0^\circ}$ $C': G(s)H(s)=\infty e^{j0^\circ}$ $D: s=\varepsilon e^{j90^\circ}$ $D': G(s)H(s)=\infty e^{-j90^\circ}$ $E: s=\infty e^{j90^\circ}$ $E': G(s)H(s)=0e^{-j180^\circ}$

$$G(s)=\frac{30*(s+8)}{s(s+2)(s+4)}\Rightarrow G(j\omega)=\frac{30*(j\omega+8)}{j\omega(j\omega+2)(j\omega+4)}$$

$$\mathrm{Im}(G(j\omega))=\frac{-30(2\omega^3+64\omega)}{\omega^6+20\omega^4+36\omega^2}=0\Rightarrow\omega^2=32$$

$$\mathrm{Re}(G(j\omega))=\left.\frac{-30\omega^2(40+\omega^2)}{\omega^6+20\omega^4+36\omega^2}\right|_{\omega^2=32}=-1.25$$

习题 3



$$A: s=\infty e^{-j90^\circ} \qquad A': G(s)H(s)=\frac{K}{s^3}=\frac{30}{\infty e^{-j90^\circ\times 3}}=0e^{j270^\circ}$$

$$B: s=\varepsilon e^{-j90^\circ} \qquad B': G(s)H(s)=\frac{1}{s}=\infty e^{j90^\circ}$$

$$C: s=\varepsilon e^{j0^\circ} \qquad C': G(s)H(s)=\infty e^{j0^\circ}$$

$$D: s=\varepsilon e^{j90^\circ} \qquad D': G(s)H(s)=\infty e^{-j90^\circ}$$

$$E: s=\infty e^{j90^\circ} \qquad E': G(s)H(s)=0e^{-j270^\circ}$$

与实轴的交点：

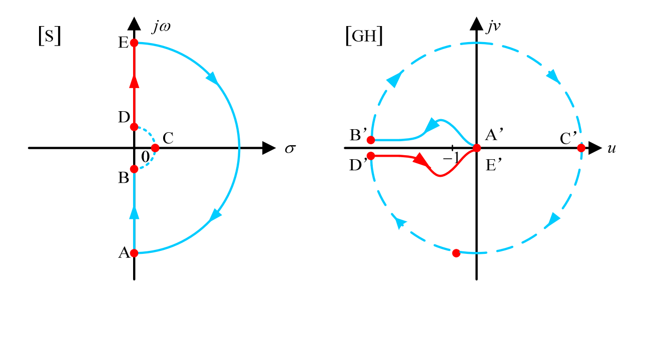
$$G(j\omega)H(j\omega)=\frac{K}{j\omega(-\omega^2+j\omega+4)}=\frac{K}{-\omega^2+j\omega(4-\omega^2)}=\frac{K[-\omega^2-j\omega(4-\omega^2)]}{\omega^4-\omega^2(4-\omega^2)^2}$$

$$\mathrm{Im}[G(j\omega)H(j\omega)]=0\Rightarrow 4-\omega^2=0\Rightarrow \omega=\pm 2$$

$$\mathrm{Re}[G(j\omega)H(j\omega)]=\left.\frac{-K\omega^2}{\omega^4-\omega^2(4-\omega^2)^2}\right|_{\omega=2}=-\frac{K}{4}$$

当 K>=4 时，P=0，N=2， Z=N+P=2 系统不稳定

当 K<4 时，P=0，N=0， Z=N+P=0 系统稳定



$$A: s=\infty e^{-j90^\circ} \qquad A': G(s)H(s)=\frac{K}{s^2}=\frac{30}{\infty e^{-j90^\circ\times 2}}=0e^{j180^\circ}$$

$$B: s=\varepsilon e^{-j90^\circ} \qquad B': G(s)H(s)=\frac{1}{s^2}=\infty e^{j180^\circ}$$

$$C: s=\varepsilon e^{j0^\circ} \qquad C': G(s)H(s)=\infty e^{j0^\circ}$$

$$D: s=\varepsilon e^{j90^\circ} \qquad D': G(s)H(s)=\infty e^{-j180^\circ}$$

$$E: s=\infty e^{j90^\circ} \qquad E': G(s)H(s)=0e^{-j180^\circ}$$

显然，Nyquist 曲线不包围(-1,0)点，因此当系统 K>0 时，系统稳定

习题 4

(1) 如果 P=0, N=2， Z=N+P=2，系统不稳定，闭环在右半平面中有 2 个特征根

(2) 如果 P=0, N=0， Z=N+P=0，系统 稳定，闭环在右半平面中有 0 个特征根

习题 5

(1)

$$\varphi(\omega)=-90^\circ-tg^{-1}(\omega)-tg^{-1}(\omega/2)=180^\circ$$

$$\Rightarrow tg^{-1}(\omega)+tg^{-1}(\omega/2)=-90^\circ\Rightarrow tg^{-1}\frac{\omega+\omega/2}{1-\omega^2/2}=-90^\circ\Rightarrow 1-\omega^2/2=0\Rightarrow \omega=\pm\sqrt{2}$$

$$|g(j\omega)|=\left.\frac{2}{|j\omega||j\omega+1|\left|\frac{j\omega}{2}+1\right|}\right|_{\omega=\pm\sqrt{2}}=\frac{2}{\sqrt{2}\sqrt{2+1}\sqrt{\frac{1}{2}+1}}=\frac{2}{3}$$

$$A(\omega)=-20\log|g(j\omega)|=3.5218dB$$

(2)

$$A(\omega) = -20\log|g(j\omega)| = 16dB \Rightarrow -20\log\frac{K/2}{|j\omega||j\omega+1|\left|\frac{j\omega}{2}+1\right|} = 16dB$$

$$\Rightarrow \log\frac{K/2}{|j\omega||j\omega+1|\left|\frac{j\omega}{2}+1\right|} = -0.8 \Rightarrow \left.\frac{K/2}{|j\omega||j\omega+1|\left|\frac{j\omega}{2}+1\right|}\right|_{\omega=\pm\sqrt{2}} = 10^{-0.8}$$

$$\Rightarrow K = 0.9509$$

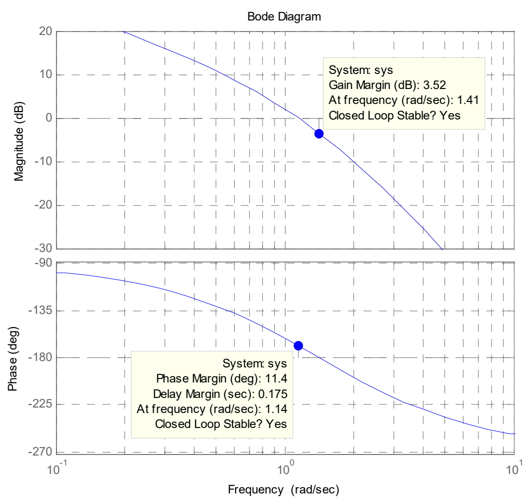
(3)

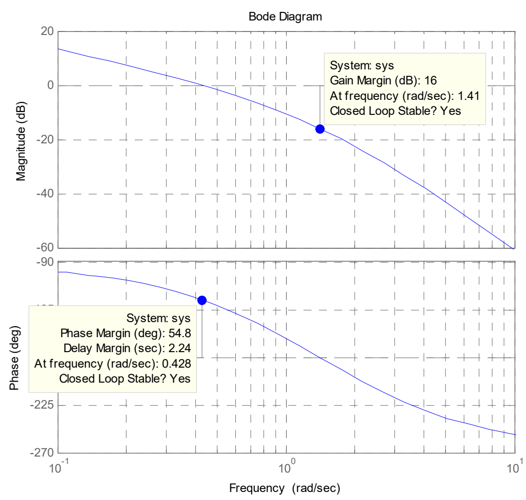
$$|g(j\omega_c)| = \frac{\sqrt{10}/2}{|j\omega_c||j\omega_c+1|\left|\frac{j\omega_c}{2}+1\right|} = 1 \Rightarrow \frac{\sqrt{10}}{\sqrt{\omega_c^2(1+\omega_c^2)(\omega_c^2+4)}} = 1 \Rightarrow \omega_c^6 + 5\omega_c^4 + 4\omega_c^2 = 10$$

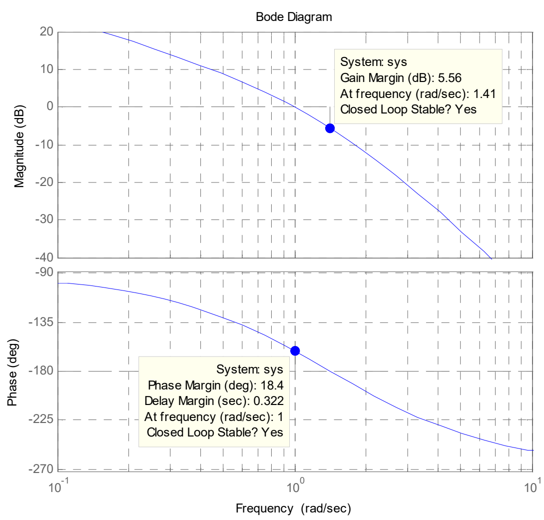
$$\Rightarrow \omega_c^2 = 1 \Rightarrow \omega_c = 1rad/\sec$$

$$\varphi(\omega_c) = -90° - tg^{-1}(\omega_c) - tg^{-1}(\omega_c/2)\Big|_{\omega_c=1} = -161.57°$$

$$\gamma = 180° + \varphi(\omega_c) = 18.43°$$







方法一：时域分析法得特征方程为

$$1+\frac{50\times\dfrac{30}{s^2(0.1s+1)}}{1+\dfrac{120s}{s^2(0.1s+1)}}=0 \quad\Rightarrow\quad 0.1s^3+s^2+120s+1500=0$$

$\because 120<1500\times 0.1 \quad \therefore$ 系统不稳定。

方法二：采用频域分析法计算。开环传递函数为

$$G_k(s)=\frac{1500(0.08s+1)}{s^2(0.1s+1)}$$

计算幅值穿越频率

$$L(\omega)=\begin{cases}20\lg\dfrac{1500}{\omega^2} & (\omega\le 10)\\ 20\lg\dfrac{1500}{\omega^2\times 0.1\omega} & (10\le\omega\le 12.5)\\ 20\lg\dfrac{1500\times 0.08\omega}{\omega^2\times 0.1\omega} & (\omega\ge 12.5)\end{cases} \quad\Rightarrow\quad 20\lg\frac{1500\times 0.08\omega_c}{\omega_c{}^2\times 0.1\omega_c}=0 \quad\Rightarrow\quad \omega_c=34.64$$

计算相角裕量

$$\gamma=180^\circ-2\times 90^\circ-\mathrm{tg}^{-1}0.1\times 34.64-\mathrm{tg}^{-1}0.08\times 34.64=-144.1^\circ<0$$

结论：系统不稳定。