Master of science-level in Mechanical Engineering
Academic Year 2019-2020, Second Semester

Automatic Control (05LSLQD, 05LSLNE)

Vito Cerone

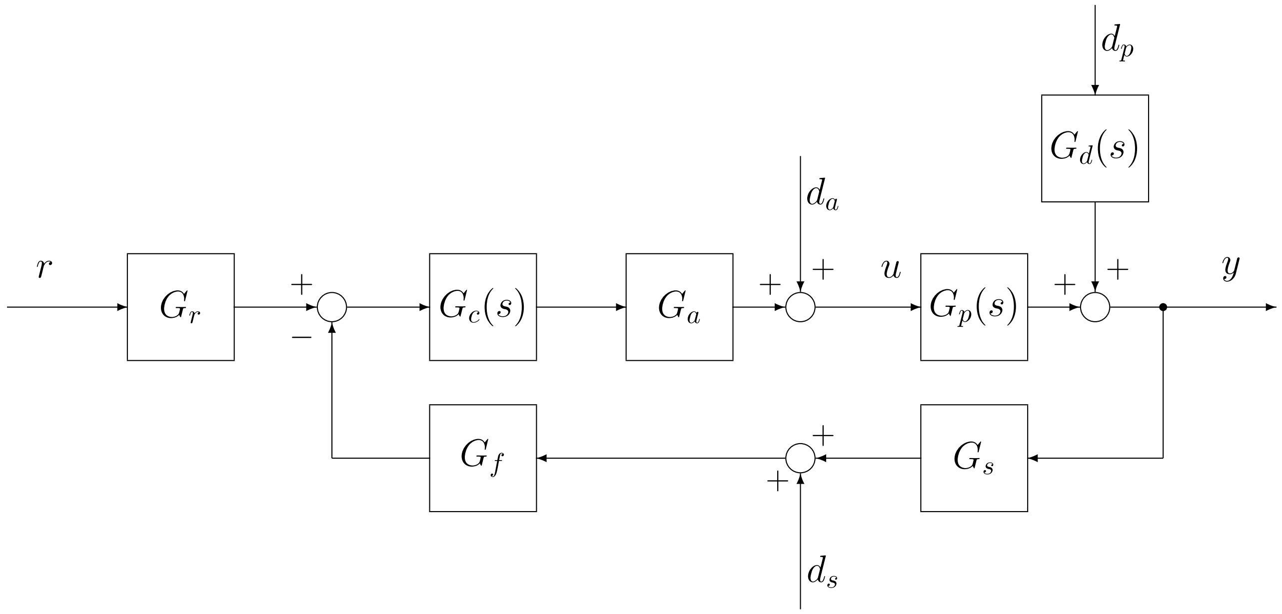
Homework n. 5

Main learning objectives

Upon successful completion of this homework, students will be able to analyze and translate transient requirements. More precisely, students will

1. Be able to valuate the damping factor of the protoype second order system from the required overshoot.
2. Be able to valuate the sensitivity peak S_{po} and the complementary sensitivity peak T_{po} of the protoype second order system from the required overshoot.
3. Be able to draw on the phase-magnitude plane, the magnitude constant curves corresponding to S_{po} and T_{po} respectively.
4. Be able to draw the Nichols plot of the frequency response of a given transfer function, together with the magnitude constant curves corresponding to S_{po} and T_{po} respectively.
5. Be able to evaluate a lower bound of ω_c (cross-over frequency) from the required rise time and the settling time.

Consider the feedback control system below.



For problem $P1$ to problem $P8$, students are asked to analyze and translate transient requirements (specifications).

Problem 1 — Given

$$G_p(s) = \frac{25}{s^3 + 3.3s^2 + 2s}$$

$G_s = 1$
$G_a = 0.095$
$G_r = 1$
$G_d(s) = 1;$
$d_a(t) = D_{a0};\ | D_{a0} | \leq 5.5 \cdot 10^{-3};$
$d_p(t) = a_p \sin(\omega_p t), \quad | a_p | \leq 2 \cdot 10^{-2}, \ \ \omega_p \leq 0.02$ rad s^{-1}.
$d_s(t) = a_s \sin(\omega_s t), \quad | a_s | \leq 10^{-1}, \ \ \omega_s \geq 40$ rad s^{-1}.

Specifications
(S1) Steady-state gain of the feedback control system: $K_d = 1$
(S2) Steady-state output error when the reference is a ramp $(R_0 = 1)$: $| e_r^\infty | \leq 1.5 \cdot 10^{-1}$
(S3) Steady-state output error in the presence of d_a: $| e_{d_a}^\infty | \leq 1.5 \cdot 10^{-2}$
(S4) Steady-state output error in the presence of d_p: $| e_{d_p}^\infty | \leq 5 \cdot 10^{-4}$.
(S5) Steady-state output error in the presence of d_s: $| e_{d_s}^\infty | \leq 5 \cdot 10^{-4}$.
(S6) Rise time: $t_r \leq 3$ s
(S7) Settling time: $t_{s,\,5\%} \leq 12$ s
(S8) Step response overshoot: $\hat{s} \leq 10\%$

Problem 2 — Given

$$G_p(s) = \frac{40}{s^2 + 3s + 4.5}$$

$G_s = 1$
$G_a = -0.09$
$G_r = 1$
$G_d(s) = 1;$
$d_a(t) = D_{a0};\ | D_{a0} | \leq 8.5 \cdot 10^{-3};$
$d_p(t) = D_{p0} t;\ | D_{p0} | \leq 3 \cdot 10^{-3};$
$d_s(t) = a_s \sin(\omega_s t), \quad | a_s | \leq 10^{-2}, \ \ \omega_s \geq 50$ rad s^{-1}.

Specifications
(S1) Steady-state gain of the feedback control system: $K_d = 1$
(S2) Steady-state output error when the reference is a ramp $(R_0 = 1)$: $| e_r^\infty | \leq 3.5 \cdot 10^{-1}$
(S3) Steady-state output error in the presence of d_a: $| e_{d_a}^\infty | \leq 1.75 \cdot 10^{-2}$
(S4) Steady-state output error in the presence of d_p: $| e_{d_p}^\infty | \leq 1 \cdot 10^{-3}$
(S5) Steady-state output error in the presence of d_s: $| e_{d_s}^\infty | \leq 2 \cdot 10^{-4}$.
(S6) Rise time: $t_r \leq 2.5$ s
(S7) Settling time: $t_{s,\,5\%} \leq 10$ s
(S8) Step response overshoot: $\hat{s} \leq 8\%$

Problem 3 — Given

$$G_p(s) = \frac{100}{s^2 + 5.5s + 4.5}$$

$G_s = 1$
$G_a = 0.014$
$G_r = 1$
$G_d(s) = 1$;
$d_a(t) = D_{a0}$; $\mid D_{a0} \mid \leq 1.5 \cdot 10^{-3}$;
$d_p(t) = a_p \sin(\omega_p t)$, $\quad \mid a_p \mid \leq 16 \cdot 10^{-2}$, $\omega_p \leq 0.03$ rad s^{-1}.
$d_s(t) = a_s \sin(\omega_s t)$, $\quad \mid a_s \mid \leq 2 \cdot 10^{-1}$, $\omega_s \geq 60$ rad s^{-1}.

Specifications
(S1) Steady-state gain of the feedback control system: $K_d = 1$
(S2) Steady-state output error when the reference is a ramp $(R_0 = 1)$: $\mid e_r^\infty \mid \leq 1.5 \cdot 10^{-1}$
(S3) Steady-state output error in the presence of d_a: $\mid e_{d_a}^\infty \mid \leq 4.5 \cdot 10^{-3}$
(S4) Steady-state output error in the presence of d_p: $\mid e_{d_p}^\infty \mid \leq 2 \cdot 10^{-3}$.
(S5) Steady-state output error in the presence of d_s: $\mid e_{d_s}^\infty \mid \leq 8 \cdot 10^{-4}$.
(S6) Rise time: $t_r \leq 2$ s
(S7) Settling time: $t_{s,\,5\%} \leq 8$ s
(S8) Step response overshoot: $\hat{s} \leq 12\%$

Problem 4 — Given

$$G_p(s) = \frac{-30}{s^3 + 3s^2 + 2s}$$

$G_s = 1$
$G_a = 0.006$
$G_r = 1$
$G_d(s) = 1$;
$d_a(t) = D_{a0}$; $\mid D_{a0} \mid \leq 2.5 \cdot 10^{-3}$;
$d_p(t) = D_{p0}t$; $\mid D_{p0} \mid \leq 8.5 \cdot 10^{-3}$;
$d_s(t) = a_s \sin(\omega_s t)$, $\quad \mid a_s \mid \leq 5 \cdot 10^{-2}$, $\omega_s \geq 40$ rad s^{-1}.

Specifications
(S1) Steady-state gain of the feedback control system: $K_d = 1$
(S2) Steady-state output error when the reference is a ramp $(R_0 = 1)$: $\mid e_r^\infty \mid \leq 2.5 \cdot 10^{-1}$
(S3) Steady-state output error in the presence of d_a: $\mid e_{d_a}^\infty \mid \leq 1 \cdot 10^{-2}$
(S4) Steady-state output error in the presence of d_p: $\mid e_{d_p}^\infty \mid \leq 1.5 \cdot 10^{-3}$
(S5) Steady-state output error in the presence of d_s: $\mid e_{d_s}^\infty \mid \leq 5 \cdot 10^{-4}$.
(S6) Rise time: $t_r \leq 3.5$ s
(S7) Settling time: $t_{s,\,5\%} \leq 14$ s
(S8) Step response overshoot: $\hat{s} \leq 15\%$

Problem 5 — Given

$$G_p(s) = \frac{25}{s^3 + 3.3s^2 + 2s}$$

$G_s = 2$
$G_a = 0.38$
$G_r = 1$
$G_d(s) = 1;$
$d_a(t) = D_{a0}t;\ |\ D_{a0}\ |\leq 5.5 \cdot 10^{-3};$
$d_p(t) = a_p \sin(\omega_p t), \quad |\ a_p\ |\leq 2 \cdot 10^{-2},\ \ \omega_p \leq 0.02$ rad s^{-1}.
$d_s(t) = a_s \sin(\omega_s t), \quad |\ a_s\ |\leq 10^{-1},\ \ \omega_s \geq 40$ rad s^{-1}.

Specifications
(S1) Steady-state gain of the feedback control system: $K_d = 4$
(S2) Steady-state output error when the reference is a ramp $(R_0 = 1)$: $|\ e_r^\infty\ | < 1.5 \cdot 10^{-1}$
(S3) Steady-state output error in the presence of d_a: $|\ e_{d_a}^\infty\ | < 5.8$
(S4) Steady-state output error in the presence of d_p: $|\ e_{d_p}^\infty\ | < 3.6 \cdot 10^{-4}$.
(S5) Steady-state output error in the presence of d_s: $|\ e_{d_s}^\infty\ | < 1.25 \cdot 10^{-4}$.
(S6) Rise time: $t_r < 2.5$ s
(S7) Settling time: $t_{s,\,5\%} < 5$ s
(S8) Step response overshoot: $\hat{s} < 12\%$

Problem 6 — Given

$$G_p(s) = \frac{40}{s^3 + 3s^2 + 4.5s}$$

$G_s = 3$
$G_a = -0.27$
$G_r = 1$
$G_d(s) = 1;$
$d_a(t) = D_{a0};\ |\ D_{a0}\ |\leq 8.5 \cdot 10^{-3};$
$d_p(t) = D_{p0}t^2;\ |\ D_{p0}\ |\leq 3 \cdot 10^{-3};$
$d_s(t) = a_s \sin(\omega_s t), \quad |\ a_s\ |\leq 10^{-2},\ \ \omega_s \geq 50$ rad s^{-1}.

Specifications
(S1) Steady-state gain of the feedback control system: $K_d = 3$
(S2) Steady-state output error when the reference is a ramp $(R_0 = 1)$: $|\ e_r^\infty\ | < 3.5 \cdot 10^{-1}$
(S3) Steady-state output error in the presence of d_a: $|\ e_{d_a}^\infty\ | < 1.75 \cdot 10^{-2}$
(S4) Steady-state output error in the presence of d_p: $|\ e_{d_p}^\infty\ | < 0.375$
(S5) Steady-state output error in the presence of d_s: $|\ e_{d_s}^\infty\ | < 3.3 \cdot 10^{-5}$.
(S6) Rise time: $t_r < 2.35$ s
(S7) Settling time: $t_{s,\,5\%} < 8$ s
(S8) Step response overshoot: $\hat{s} \leq 9\%$

Problem 7 — Given

$$G_p(s) = \frac{100}{s^3 + 5.5s^2 + 4.5s}$$

$G_s = 0.5$
$G_a = 0.112$
$G_r = 1$
$G_d(s) = 1;$
$d_a(t) = D_{a0}t; \mid D_{a0} \mid \leq 1.5 \cdot 10^{-3};$
$d_p(t) = a_p \sin(\omega_p t), \quad \mid a_p \mid \leq 16 \cdot 10^{-2}, \ \ \omega_p \leq 0.03$ rad s^{-1}.
$d_s(t) = a_s \sin(\omega_s t), \quad \mid a_s \mid \leq 2 \cdot 10^{-1}, \ \ \omega_s \geq 60$ rad s^{-1}.

Specifications
(S1) Steady-state gain of the feedback control system: $K_d = 8$
(S2) Steady-state output error when the reference is a ramp $(R_0 = 1)$: $\mid e_r^\infty \mid < 1.5 \cdot 10^{-1}$
(S3) Steady-state output error in the presence of d_a: $\mid e_{d_a}^\infty \mid < 2.14$
(S4) Steady-state output error in the presence of d_p: $\mid e_{d_p}^\infty \mid < 5.1 \cdot 10^{-3}$.
(S5) Steady-state output error in the presence of d_s: $\mid e_{d_s}^\infty \mid < 1.6 \cdot 10^{-3}$.
(S6) Rise time: $t_r < 1.8$ s
(S7) Settling time: $t_{s,\,5\%} < 6$ s
(S8) Step response overshoot: $\hat{s} < 13\%$

Problem 8 — Given

$$G_p(s) = \frac{-30}{s^3 + 3s^2 + 2s}$$

$G_s = 10$
$G_a = 0.06$
$G_r = 1$
$G_d(s) = 1;$
$d_a(t) = D_{a0}; \mid D_{a0} \mid \leq 2.5 \cdot 10^{-3};$
$d_p(t) = D_{p0}t^2; \mid D_{p0} \mid \leq 8.5 \cdot 10^{-3};$
$d_s(t) = a_s \sin(\omega_s t), \quad \mid a_s \mid \leq 5 \cdot 10^{-2}, \ \ \omega_s \geq 40$ rad s^{-1}.

Specifications
(S1) Steady-state gain of the feedback control system: $K_d = 10$
(S2) Steady-state output error when the reference is a ramp $(R_0 = 1)$: $\mid e_r^\infty \mid < 2.5 \cdot 10^{-1}$
(S3) Steady-state output error in the presence of d_a: $\mid e_{d_a}^\infty \mid < 1 \cdot 10^{-2}$
(S4) Steady-state output error in the presence of d_p: $\mid e_{d_p}^\infty \mid < 0.94$
(S5) Steady-state output error in the presence of d_s: $\mid e_{d_s}^\infty \mid < 1.6 \cdot 10^{-5}$.
(S6) Rise time: $t_r < 2.5$ s
(S7) Settling time: $t_{s,\,5\%} < 13$ s
(S8) Step response overshoot: $\hat{s} < 14\%$

Problem 9

Draw the Nichols plot of the frequency response of the transfer functions listed below, together with the magnitude constant curves corresponding to S_{po} and T_{po}. To this end, students may want to consider values of S_{po} and T_{po} derived from overshoot requirements randomly generated in the range from 5% to 15%.

$$H(s) = \frac{1}{s(s+2)(s+4)} \tag{1}$$

$$H(s) = \frac{-0.1(1-2s)}{s(s+0.2)(1+s)} \tag{2}$$

$$H(s) = \frac{1}{s^2(s+3)} \tag{3}$$

$$H(s) = \frac{2(1+0.5s)}{(1+s)(1-s)^2} \tag{4}$$

$$H(s) = \frac{s^2+1}{(s-2)(s+2)(s+4)} \tag{5}$$

$$H(s) = \frac{0.125(1+s^2)}{s(1+0.25s)(1+0.5s)} \tag{6}$$

$$Hs) = \frac{s-2}{(s+2)(s^2+1)} \tag{7}$$

$$H(s) = \frac{0.25}{s(1-0.5s)^2} \tag{8}$$

$$H(s) = \frac{1}{(s^2+1)(s+2)} \tag{9}$$

$$H(s) = \frac{-(1-s)}{s(1+s^2)} \tag{10}$$

$$H(s) = \frac{s+1}{(s+2)(s^2+4s+5)} \tag{11}$$

$$H(s) = \frac{(s+3)(s^2+2s+2)}{s(s-1)(s+2)(s+4)} \tag{12}$$

$$H(s) = \frac{1}{2s^3} \tag{13}$$

$$H(s) = \frac{s^3+4s^2+7s+6}{s^4+5s^3+10s^2+11s+3} \tag{14}$$

$$H(s) = \frac{(s^2-1)}{s^3+s^2+s-3} \tag{15}$$

Some results of given problems

Problem P1

(S2) $| e_r^\infty | \leq 1.5 \cdot 10^{-1} \Rightarrow \nu \geq 0, \quad | K_c | \geq 5.614$
(S3) $| e_{d_a}^\infty | \leq 1.5 \cdot 10^{-2} \Rightarrow \nu \geq 0, \quad | K_c | \geq 3.8596$
(S4) $| e_{d_p}^\infty | \leq 5 \cdot 10^{-4} \Rightarrow M_S^{LF} \approx -32$ dB, $\omega_c \geq 0.25$ rad/s.
(S5) $| e_{d_s}^\infty | \leq 5 \cdot 10^{-4} \Rightarrow M_T^{HF} \approx -46$ dB, $\omega_c \leq 1.4$ rad/s.
(S6) $t_r \leq 3 \Rightarrow \omega_c \geq 0.66$ rad/s
(S7) $t_s \leq 12 \Rightarrow \omega_c \geq 0.31$ rad/s
(S8) $\hat{s} \leq 10\% \Rightarrow \zeta \geq 0.59, \quad T_{po} \leq 1.049 = 0.41$ dB, $\quad S_{po} \leq 1.361 = 2.7$ dB

Problem P2

(S2) $| e_r^\infty | \leq 3.50 \cdot 10^{-1} \Rightarrow \nu \geq 1, \quad | K_c | \geq 3.5714$
(S3) $| e_{d_a}^\infty | \leq 1.75 \cdot 10^{-2} \Rightarrow \nu \geq 0$. Due to (S2), $\nu \geq 1 \Rightarrow | e_{d_a}^\infty | = 0$ and no constraints on $| K_c |$.
(S4) $| e_{d_p}^\infty | \leq 1.00 \cdot 10^{-3} \Rightarrow \nu \geq 1, \quad | K_c | \geq 3.75$
(S5) $| e_{d_s}^\infty | \leq 2 \cdot 10^{-4} \Rightarrow M_T^{HF} \approx -34$ dB, $\omega_c \leq 3.5$ rad/s.
(S6) $t_r \leq 2.5 \Rightarrow \omega_c \geq 0.81$ rad/s
(S7) $t_s \leq 10 \Rightarrow \omega_c \geq 0.33$ rad/s
(S8) $\hat{s} \leq 8\% \Rightarrow \zeta \geq 0.63, \quad T_{po} \leq 1.024 = 0.21$ dB, $\quad S_{po} \leq 1.33 = 2.5$ dB

Problem P3

(S2) $| e_r^\infty | \leq 1.5 \cdot 10^{-1} \Rightarrow \nu \geq 1, \quad | K_c | \geq 21.429$
(S3) $| e_{d_a}^\infty | \leq 4.5 \cdot 10^{-3} \Rightarrow \nu \geq 0$. Due to (S2), $\nu \geq 1 \Rightarrow | e_{d_a}^\infty | = 0$ and no constraints on $| K_c |$.
(S4) $| e_{d_p}^\infty | \leq 2 \cdot 10^{-3} \Rightarrow M_S^{LF} \approx -38$ dB, $\omega_c \geq 0.54$ rad/s.
(S5) $| e_{d_s}^\infty | \leq 8 \cdot 10^{-4} \Rightarrow M_T^{HF} \approx -48$ dB, $\omega_c \leq 1.9$ rad/s.
(S6) $t_r \leq 2 \Rightarrow \omega_c \geq 0.972$ rad/s
(S7) $t_s \leq 8 \Rightarrow \omega_c \geq 0.498$ rad/s
(S8) $\hat{s} \leq 12\% \Rightarrow \zeta \geq 0.56, \quad T_{po} \leq 1.078 = 0.65$ dB, $\quad S_{po} \leq 1.39 = 2.9$ dB

Problem P4

(S2) $| e_r^\infty | \leq 2.5 \cdot 10^{-1} \Rightarrow \nu \geq 0, \quad | K_c | \geq 44.4$
(S3) $| e_{d_a}^\infty | \leq 1.0 \cdot 10^{-2} \Rightarrow \nu \geq 0, \quad | K_c | \geq 41.6$
(S4) $| e_{d_p}^\infty | \leq 1.5 \cdot 10^{-3} \Rightarrow \nu \geq 0, \quad | K_c | \geq 62.963$
(S5) $| e_{d_s}^\infty | \leq 5 \cdot 10^{-4} \Rightarrow M_T^{HF} \approx -40$ dB, $\omega_c \leq 2$ rad/s.
(S6) $t_r \leq 3.5 \Rightarrow \omega_c \geq 0.55$ rad/s
(S7) $t_s \leq 14 \Rightarrow \omega_c \geq 0.32$ rad/s
(S8) $\hat{s} \leq 15\% \Rightarrow \zeta \geq 0.52, \quad T_{po} \leq 1.13 = 1.1$ dB, $\quad S_{po} \leq 1.45 = 3.2$ dB

Problem P5

(S2) $\mid e_r^\infty \mid \leq 1.5 \cdot 10^{-1} \Rightarrow \nu \geq 0.$ Due to (S3), $\nu \geq 1 \Rightarrow \mid e_r^\infty \mid = 0$ and no constraints on $\mid K_c \mid$.
(S3) $\mid e_{d_a}^\infty \mid \leq 5.8 \qquad \Rightarrow \nu \geq 1, \quad \mid K_c \mid \geq 0.01$
(S4) $\mid e_{d_p}^\infty \mid \leq 3.6 \cdot 10^{-4} \Rightarrow M_S^{LF} \approx -35$ dB, $\omega_c \geq 0.30$ rad/s.
(S5) $\mid e_{d_s}^\infty \mid \leq 1.25 \cdot 10^{-4} \Rightarrow M_T^{HF} \approx -52$ dB, $\omega_c \leq 1$ rad/s.
(S6) $t_r \leq 2.5 \Rightarrow \omega_c \geq 0.78$ rad/s
(S7) $t_s \leq 5 \Rightarrow \omega_c \geq 0.80$ rad/s
(S8) $\hat{s} \leq 12\% \Rightarrow \zeta \geq 0.56, \quad T_{po} \leq 1.078 = 0.65$ dB, $\quad S_{po} \leq 1.39 = 2.9$ dB

Problem P6

(S2) $\mid e_r^\infty \mid \leq 3.5 \cdot 10^{-1} \Rightarrow \nu \geq 0.$ Due to (S4), $\nu \geq 1 \Rightarrow \mid e_r^\infty \mid = 0$ and no constraints on $\mid K_c \mid$.
(S3) $\mid e_{d_a}^\infty \mid \leq 1.75 \cdot 10^{-2} \Rightarrow \nu \geq 0.$ Due to (S4), $\nu \geq 1 \Rightarrow \mid e_{d_a}^\infty \mid = 0$ and no constraints on $\mid K_c \mid$.
(S4) $\mid e_{d_p}^\infty \mid \leq 0.375 \Rightarrow \nu \geq 1, \quad \mid K_c \mid \geq 0.01$
(S5) $\mid e_{d_s}^\infty \mid \leq 3.3 \cdot 10^{-5} \Rightarrow M_T^{HF} \approx -40$ dB, $\omega_c \leq 2.49$ rad/s.
(S6) $t_r \leq 2.35 \Rightarrow \omega_c \geq 0.85$ rad/s
(S7) $t_s \leq 8 \Rightarrow \omega_c \geq 0.44$ rad/s
(S8) $\hat{s} \leq 9\% \Rightarrow \zeta \geq 0.61, \quad T_{po} \leq 1.036 = 0.30$ dB, $\quad S_{po} \leq 1.35 = 2.58$ dB

Problem P7

(S2) $\mid e_r^\infty \mid \leq 1.5 \cdot 10^{-1} \Rightarrow \nu \geq 0.$ Due to (S3), $\nu \geq 1 \Rightarrow \mid e_r^\infty \mid = 0$ and no constraints on $\mid K_c \mid$.
(S3) $\mid e_{d_a}^\infty \mid \leq 2.14 \qquad \Rightarrow \nu \geq 1, \quad \mid K_c \mid \geq 0.0501$
(S4) $\mid e_{d_p}^\infty \mid \leq 5.1 \cdot 10^{-3} \Rightarrow M_S^{LF} \approx -30$ dB, $\omega_c \geq 0.34$ rad/s.
(S5) $\mid e_{d_s}^\infty \mid \leq 1.6 \cdot 10^{-3} \Rightarrow M_T^{HF} \approx -48$ dB, $\omega_c \leq 1.90$ rad/s.
(S6) $t_r \leq 1.8 \Rightarrow \omega_c \geq 1.07$ rad/s
(S7) $t_s \leq 6 \Rightarrow \omega_c \geq 0.80$ rad/s
(S8) $\hat{s} \leq 13\% \Rightarrow \zeta \geq 0.54, \quad T_{po} \leq 1.095 = 0.79$ dB, $\quad S_{po} \leq 1.41 = 2.99$ dB

Problem P8

(S2) $\mid e_r^\infty \mid \leq 2.5 \cdot 10^{-1} \Rightarrow \nu \geq 0.$ Due to (S4), $\nu \geq 1 \Rightarrow \mid e_r^\infty \mid = 0$ and no constraints on $\mid K_c \mid$.
(S3) $\mid e_{d_a}^\infty \mid \leq 1 \cdot 10^{-2} \Rightarrow \nu \geq 0.$ Due to (S4), $\nu \geq 1 \Rightarrow \mid e_{d_a}^\infty \mid = 0$ and no constraints on $\mid K_c \mid$.
(S4) $\mid e_{d_p}^\infty \mid \leq 0.94 \Rightarrow \nu \geq 1, \quad \mid K_c \mid \geq 0.1005$
(S5) $\mid e_{d_s}^\infty \mid \leq 1.6 \cdot 10^{-5} \Rightarrow M_T^{HF} \approx -50$ dB, $\omega_c \leq 1.13$ rad/s.
(S6) $t_r \leq 2.5 \Rightarrow \omega_c \geq 0.77$ rad/s
(S7) $t_s \leq 13 \Rightarrow \omega_c \geq 0.33$ rad/s
(S8) $\hat{s} \leq 14\% \Rightarrow \zeta \geq 0.53, \quad T_{po} \leq 1.111 = 0.92$ dB, $\quad S_{po} \leq 1.43 = 3.09$ dB

Useful Matlab commands

Following is a list of commands which are useful for this homework. If you type `help control`, you get the complete list of commands included in the Control System Toolbox of Matlab. Use `help` in MATLAB for more information on how to use any of these commands.

- `help`: Matlab help documentation.
- `figure`: Create a new figure or redefine the current figure, see also subplot, axis.
- `hold`: Hold the current graph, see also figure.
- `axis`: Set the scale of the current plot, see also plot, figure.
- `plot`: Draw a plot, see also figure, axis, subplot.
- `xlabel/ylabel`: Add a label to the horizontal/vertical axis of the current plot, see also title, text, gtext.
- `title`: Add a title to the current plot.
- `text`: Add a piece of text to the current plot, see also title, xlabel, ylabel, gtext.
- `subplot`: Divide the plot window up into pieces, see also plot, figure.
- `abs`: returns the absolute value of of a complex number.
- `angle`: returns the phase angles, in radians, of a complex number.
- `squeeze`: Remove singleton dimensions.
- `bode`: Draw the Bode plot, see also logspace, margin, nyquist1.
- `nyquist`: Draw the Nyquist plot.
- `nyquist1`: Draw the Nyquist plot, see also nyquist. Note this command was written to replace the MATLAB standard command nyquist to get more accurate Nyquist plots.
- `grid`: Draw the grid lines on the current plot.
- `logspace`: Provides logarithmically spaced vector.
- `dcgain`: Computes the steady-state (D.C. or low frequency) gain of LTI models.
- `tf`: Creation of transfer functions or conversion to transfer function. `s = tf('s')` specifies the transfer function $H(s) = s$ (Laplace variable).
- `zpk`: Create zero-pole-gain models or convert to zero-pole-gain format.
- `minreal`: Minimal realization and pole-zero cancellation.
- `tfdata`: Quick access to transfer function data. `[num,den] = tfdata(sys)` returns the numerator(s) and denominator(s) of the transfer function `sys`.
- `nichols` : Draws the Nichols plot of the frequency response of LTI models.
- `myngridst` : Draws the constant magnitude loci related to T_{po} (complementary sensitivity resonance peak) and S_{po} (sensitivity resonance peak) on the Nichols plane. This is not a native matlab command. This matlab function is provided by the teacher and should be copied in the working directory.