1)

3 Curvas

A - tende para ∞

B - tende para 0.8

C - tende para -0.5

A: Não há muito a dizer, é instável => polo no spcd

se a derivada na origem for 0 é de 2ª ordem

Caso contrário é de 1ª.

B: $G(0)=0.8$

$t(2\%)=0.35=\frac{4}{a} \Leftrightarrow a=\frac{4}{0.35}\approx 11$

$\frac{x}{11}=0.8 \Leftrightarrow x=8.8$

$G(s)\approx \frac{8.8}{s+11}$

C: $G(0)=-0.5$

$t(2\%)=0.7=\frac{4}{a} \Leftrightarrow a=\frac{4}{0.7}\approx 6$

$\frac{x}{6}=-0.5 \Leftrightarrow x=-3$

$G(s)\approx \frac{-3}{s+6}$

2)

a) $H(s)=\frac{121}{s^2+13.2s+121}$

$121=w_n^2 \Leftrightarrow w_n=11$

$2\xi w_n=13.2 \Leftrightarrow \xi=\frac{13.2}{22}=0.6$

$w_d=w_n\sqrt{1-\xi^2}=8.8$

$t_s(2\%)\approx\frac{4}{\xi w_n}\approx 0.6$

$t_p=\frac{\pi}{w_d}\approx 0.357$

$S\%=100\,e^{-\frac{\xi\pi}{\sqrt{1-\xi^2}}}\approx 9.5\%$

b) $H(s)=\frac{0.04}{s^2+0.02s+0.04}$

$w_n^2=0.04 \Leftrightarrow w_n=0.2$

$2\xi w_n=0.02 \Leftrightarrow \xi=0.05$

$w_d=w_n\sqrt{1-\xi^2}=0.19975$

$t_p=\frac{\pi}{w_d}=15.7276$

$t_s(2\%)\approx\frac{4}{\xi w_n}=400$

$S\%=100\,e^{-\frac{\xi\pi}{\sqrt{1-\xi^2}}}\approx 85.4468\%$

c) $H(s)=\frac{1.05\times10^7}{s^2+1.6\times10^3 s+1.05\times10^7}$

$w_n^2=1.05\times10^7 \Leftrightarrow w_n=3240.37$

$2\xi w_n=1.6\times10^3 \Leftrightarrow \xi=0.24688$

$w_d=w_n\sqrt{1-\xi^2}=314.324$

$t_p=\frac{\pi}{w_d}\approx 0.01$

$t_s(2\%)\approx\frac{4}{\xi w_n}=0.005$

$S\%=100\,e^{-\frac{\xi\pi}{\sqrt{1-\xi^2}}}=44.9162\%$

3)

a)

$\frac{X_1}{A_{ext}}=-\frac{1}{s^2+\frac{b}{m}s+\frac{2K}{m}}=-\frac{1}{s^2+17s+200}$

b) $Y(t)=1-\frac{1}{\sqrt{1-\xi^2}}e^{-\xi w_n t}\sin(w_n\sqrt{1-\xi^2}\,t+\psi)$

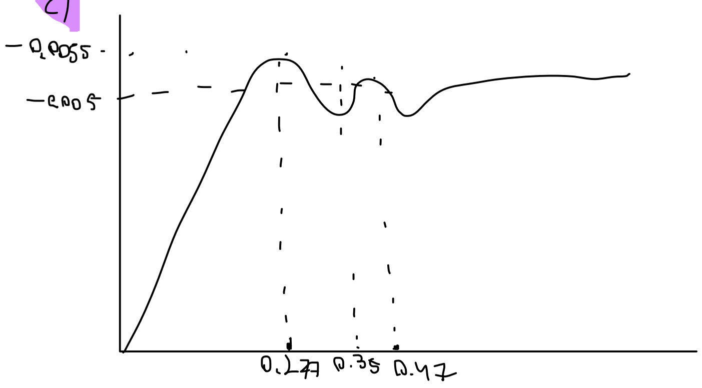
$w_n^2=200 \Leftrightarrow w_n=\sqrt{200}$

$2\xi w_n=17 \Leftrightarrow \xi=\frac{17}{2\cdot10\sqrt{2}}=\frac{17}{40}\sqrt{2}$

$\psi=\operatorname{arctg}\frac{\sqrt{1-\xi^2}}{\xi}=0.925$

$Y(t)=1-\frac{1}{\sqrt{1-\xi^2}}e^{-\xi w_n t}\cos(w_n\sqrt{1-\xi^2}\,t-0.65)=-\frac{1}{200}+0.0063\,e^{-8.5t}\cos(11.3t-0.65)$

c)



$t_s(2\%)=\frac{4}{\xi w_n}\approx 0.47\,s$

$t_s(5\%)=\frac{3}{\xi w_n}\approx 0.35\,s$

$t_p=\frac{\pi}{w_d}=0.277\,s$

$w_d=w_n\sqrt{1-\xi^2}$

$S\%=100\,e^{-\frac{\xi\pi}{\sqrt{1-\xi^2}}}=9.4\%$

d) $2\xi w_n=\frac{b}{m} \Leftrightarrow \xi=\frac{b}{m2}\cdot\sqrt{\frac{m}{2K}} \Leftrightarrow \xi=\frac{b\sqrt{m}}{2m\sqrt{2K}}$

$\xi\uparrow \Leftrightarrow S\%\downarrow \Rightarrow \uparrow b;\ \downarrow K;\ \downarrow m$

|parte real dos polos| $\uparrow\ \Rightarrow\ t_s\downarrow$

$\Updownarrow$

$\xi w_n\uparrow$

$\xi w_n=\frac{b}{2m}\uparrow \Leftrightarrow b\uparrow;\ m\downarrow$

4) $H(s)=\frac{X(s)}{1+X(s)}=\frac{\frac{K}{s(Ts+1)}}{1+\frac{K}{s(Ts+1)}}=\frac{\frac{K}{s(Ts+1)}}{\frac{s(Ts+1)+K}{s(Ts+1)}}=\frac{K}{Ts^2+s+K}=\frac{\frac{K}{T}}{s^2+\frac{s}{T}+\frac{K}{T}}$

$w_n=\sqrt{\frac{K}{T}}$

$2\xi w_n=\frac{1}{T} \Leftrightarrow \xi=\frac{1}{2T}\sqrt{\frac{T}{K}}=\frac{1}{2\sqrt{TK}}$

$w_d=\sqrt{\frac{K}{T}}\cdot\sqrt{1-\frac{1}{4TK}}=\sqrt{\frac{K}{T}-\frac{1}{4T^2}}$

$t_p=\frac{\pi}{w_d} \Leftrightarrow 3=\frac{\pi}{w_d}=\frac{\pi}{\sqrt{\frac{K}{T}-\frac{1}{4T^2}}}$

$S\%=e^{-\xi w_n t_p}$

$S\%=25.4\%=100\,e^{-\frac{\xi\pi}{\sqrt{1-\xi^2}}}$

$\begin{cases} 25.4=100\,e^{\frac{-\frac{1}{2\sqrt{TK}}\cdot\pi}{\sqrt{1-\frac{1}{4TK}}}} \\ 3=\frac{\pi}{\sqrt{\frac{K}{T}-\frac{1}{4T^2}}} \end{cases} \Leftrightarrow \begin{matrix} T\approx 1.09 \\ K\approx 1.42 \end{matrix}$

5)

a) $J_m \ddot{\theta}_m + \left(b + \frac{K_t K_e}{R_a}\right)\dot{\theta}_m = \frac{K_t}{R_a} v_a$

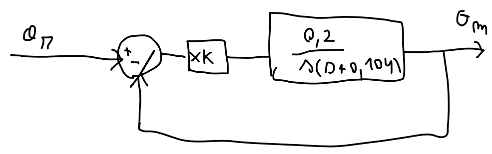
$$\frac{\dot{\Omega}_m}{V_a} = \frac{\frac{K_t}{R_a}}{J_m s + b + \frac{K_t K_e}{R_a}} = \frac{0,2}{s + 0,104}$$

b) $A_0 = G(0) = \frac{0,2}{0,104}$

$\dot{\theta}_m = 10 \cdot A_0 = \frac{2}{0,104} = 19 \text{ rad/s}$

c) $$\frac{\Omega_m}{V_a} = \frac{\frac{K_t}{R_a}}{s\left(J_m s + b + \frac{K_t K_e}{R_a}\right)} = \frac{0,2}{s(s+0,104)}$$

d)



$$H(s) = \frac{0,2K}{s^2 + 0,104s + 0,2K}$$

e) $S\% = 100\, e^{\frac{-\zeta w_n t_p}{}}$

$$\ln\left(\frac{20}{100}\right) = \frac{-\zeta\pi}{\sqrt{1-\zeta^2}} \Leftrightarrow \ln\left(\frac{20}{100}\right) + \frac{\zeta\pi}{\sqrt{1-\zeta^2}} = 0 \Leftrightarrow$$

$$\Leftrightarrow \ln\left(\frac{20}{100}\right)\sqrt{1-\zeta^2} - \zeta\pi = 0 \Leftrightarrow$$

$$\Leftrightarrow \ln\left(\frac{20}{100}\right)\sqrt{1-\zeta^2} = \zeta\pi \Leftrightarrow$$

$$\Leftrightarrow \ln\left(\frac{20}{100}\right)^2 (1-\zeta^2) = \zeta^2\pi^2 \Leftrightarrow$$

$$\Leftrightarrow \frac{\ln\left(\frac{20}{100}\right)^2}{\pi^2 + \ln\left(\frac{20}{100}\right)^2} = \zeta^2 \Leftrightarrow \zeta = \sqrt{\frac{\ln\left(\frac{20}{100}\right)^2}{\pi^2 + \ln\left(\frac{20}{100}\right)^2}} = 0.456$$

$$2\zeta w_n = 0.104 \Leftrightarrow w_n = \frac{0.104}{2\zeta}$$

$$w_n = \sqrt{0,2K} \Leftrightarrow \frac{\left(\frac{0.104}{2\zeta}\right)^2}{0,2} = K = 0.065$$

$S < 20\% \Rightarrow \zeta < 0.456 \Rightarrow K < 0.065$

6) a) $H(s) = \frac{5}{s(s^2+2s+5)}$

$w_n = \sqrt{5}$ $\quad \varphi = \arctan\left(\frac{\sqrt{1-\zeta^2}}{\zeta}\right)$

$\zeta = \frac{1}{\sqrt{5}}$

$$y(t) = 1 - \frac{1}{\sqrt{1-\zeta^2}} e^{-\zeta w_n t} \sin\left(w_n\sqrt{1-\zeta^2}\, t + \varphi\right) \quad t \geq 0$$

b) usam Matlab :3

7) $G(s) = \frac{Y(s)}{R(s)} = \frac{k}{(s+p)(s^2+as+b)}$

a) $$\bar{G}(s) = \frac{k}{(s+p)(s^2+as+b)} \approx \frac{\frac{k}{p}}{(s^2+as+b)} \quad \text{Com } p > 5 \cdot \left|\frac{a}{2}\right|$$

$2\% \leq S\% \leq 10\%$

$$S_{2\%} \quad \zeta = \sqrt{\frac{\ln\left(\frac{2}{100}\right)^2}{\pi^2 + \ln\left(\frac{2}{100}\right)^2}} = 0.7797$$

$S_{10\%}$ $\zeta = 0.5912$

$\theta_{10\%} = \arccos(S_{10\%} \zeta) = 36.24°$

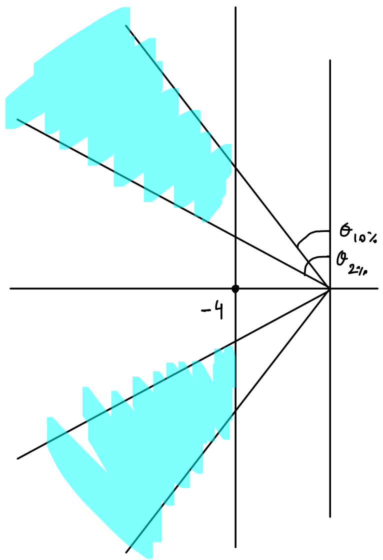
$\theta_{2\%} = \arccos(S_{2\%} \zeta) = 51.23°$

//

$t_s(2\%) \leq 1 \Leftrightarrow \frac{4}{\zeta w_n} \leq 1 \Leftrightarrow \zeta w_n \geq 4$

//

Valor final $= 1$: $\bar{G}(0) = \frac{K}{pb} = 1$



b) $2\zeta w_n = a$

$\zeta w_n = \frac{a}{2}$

$a = 10 = \zeta w_n$ $\quad \zeta = \frac{2}{3} \approx 0.666\ldots$

$b = w_n^2$ $\quad w_n = 15$ $\quad b = 225$

$a = 10$

$b = 225$

$p = 30$

$k = 6750$

8) b) $$\frac{\frac{K\,1/2}{s+1/12}}{\frac{s+1/12 + K\,1/2}{s+1/12}} = \underbrace{\frac{K\,1/2}{s + \frac{1}{12} + K\frac{1}{2}}}_{H(s)}$$

$K=1$: $\frac{1/2}{s(s+7/12)} \overset{TL^{-1}}{\rightsquigarrow} \frac{6}{7}\left(1-e^{-\frac{7}{12}t}\right)u(t)$

$K=2$: $\frac{1}{s(s+\frac{13}{12})} \overset{TL^{-1}}{\rightsquigarrow} \frac{12}{13}\left(1-e^{-\frac{13}{12}t}\right)u(t)$

c) $\frac{K\,1/2}{s+\frac{1}{12}-K\frac{1}{2}}$ $\quad K=1$ $\quad \frac{1/2}{s(s-\frac{5}{12})} \overset{TL^{-1}}{\rightsquigarrow} \frac{6}{5}\left(e^{\frac{5t}{12}}-1\right)$

$K=2$ $\quad \frac{1}{s(s-\frac{11}{12})} \overset{TL^{-1}}{\rightsquigarrow} \frac{12}{11}\left(e^{\frac{11t}{12}}-1\right)$

d) $S(s) = R(s) \cdot H(s)$

$R(s) = \frac{1}{s} + \frac{1}{\frac{sK}{r}} \ldots$

$K=1$: $\frac{1}{s(s+7/12)} \overset{TL^{-1}}{\rightsquigarrow} \frac{12}{7}\left(1-e^{-\frac{7t}{12}}\right)$

$K=2$: $\frac{1}{s} + \frac{1}{2s} = \frac{3}{2s} \Rightarrow \frac{3}{2s} \cdot \left(\frac{1}{s+\frac{13}{12}}\right) \overset{TL^{-1}}{\rightsquigarrow} \frac{18}{13}\left(1-e^{-\frac{13t}{12}}\right)$

b) $k = \frac{1}{s}$

e) $\frac{1/2}{s^2(s+7/12)} \overset{TL^{-1}}{\rightsquigarrow} -\frac{72}{49} + \frac{6}{7}t + \frac{72}{49}e^{-\frac{7t}{12}}$

$K = \frac{2}{s}$

$\frac{1}{s^2(s+13/12)} \overset{TL^{-1}}{\rightsquigarrow} -\frac{144}{169} + \frac{12}{13}t + \frac{144}{169}e^{-\frac{13t}{12}}$

d) $k = \frac{1}{s}$

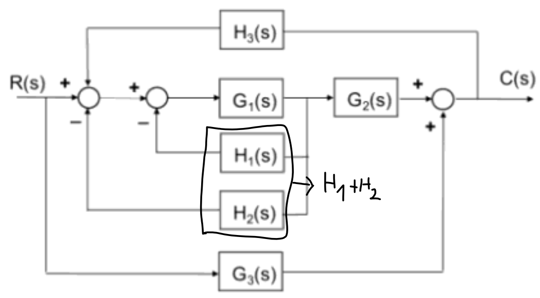
$\frac{3}{2s^2(s+\frac{13}{12})} \overset{TL^{-1}}{\rightsquigarrow} -\frac{144}{49} + \frac{12}{7}t + \frac{144}{49}e^{-\frac{7t}{12}}$

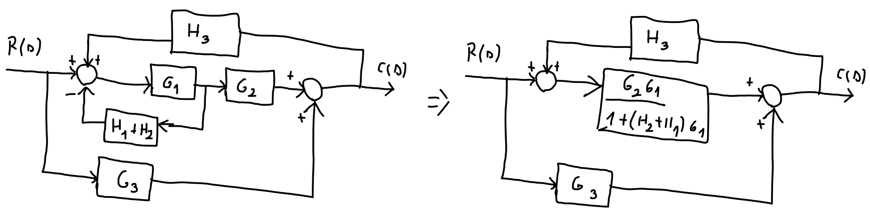
$K = \frac{2}{s}$

$-\frac{216}{169} + \frac{18}{13}t + \frac{216}{169}e^{-\frac{13t}{12}}$

f) → Noutra página

9) a)





$$\left(\frac{G_2 G_1}{1+(H_2+H_1)G_1} + G_3\right) \cdot \left(\frac{1}{1 - \frac{G_2 G_1 H_3}{1+(H_2+H_1)G_1}}\right) = \frac{G_3 + G_1 G_2 + G_1 G_3 (H_1+H_2)}{1+\cancel{G_1(H_1+H_2)}} \cdot \frac{1+\cancel{(H_1+H_2)}G_1}{1+(H_1+H_2)G_1 - G_2 G_1 H_3}$$

$$\frac{C(s)}{R(s)} = \frac{G_3 + G_1 G_2 + G_1 G_3 (H_1+H_2)}{1+(H_1+H_2)G_1 - G_2 G_1 H_3}$$

b) → Próxima página

10) a) $$H(s) = \frac{G(s)}{1+G(s)} = \frac{\frac{5000}{s^2+75s}}{\frac{s^2+75s+5000}{s^2+75s}} = \frac{5000}{s^2+75s+5000}$$

$$\begin{cases} w_n^2 = 5000 \\ 2\zeta w_n = 75 \end{cases} \Leftrightarrow \begin{cases} w_n = \sqrt{5000} \\ \zeta = 0.53 \end{cases}$$

$S\% = 100\, e^{\frac{-\zeta\pi}{\sqrt{1-\zeta^2}}} = 14\%$

b) $t_s(2\%) = \frac{4}{\zeta w_n} = 0.107s$

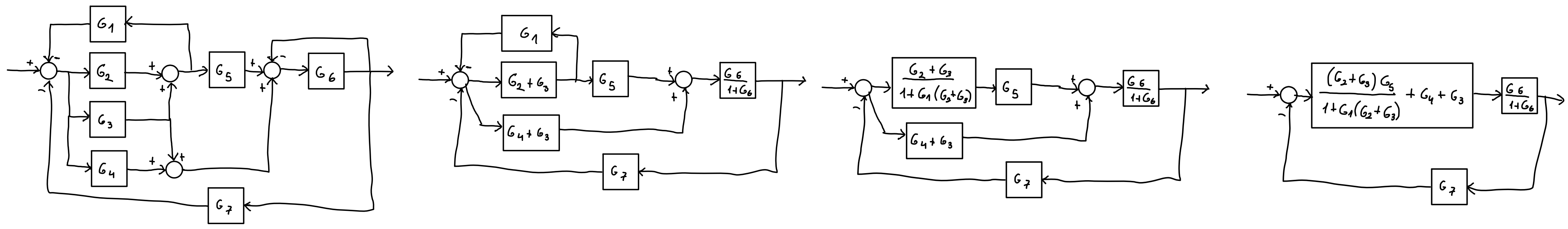
c) $E(s) = \frac{1}{1+G(s)} \cdot R(s)$

$e = \lim_{s\to 0} s \cdot \frac{1}{1+G(s)} \cdot R(s) = \frac{1}{1+G(0)} = 0$

d) $e = \lim_{s\to 0} s \cdot \frac{1}{1+G(s)} \cdot \frac{5}{s^2} = 0.075$

e) $e = \lim_{s\to 0} s \cdot \frac{1}{1+G(s)} \cdot \frac{10}{s^3} = \infty$

b)



$$\frac{C(s)}{R(s)} = \frac{\left[\frac{(G_2+G_3)G_5}{1+G_1(G_2+G_3)} + G_4 + G_3\right]\cdot\frac{G_6}{1+G_6}}{1+\left[\frac{(G_2+G_3)G_5}{1+G_1(G_2+G_3)} + G_4 + G_3\right]\cdot\frac{G_6}{1+G_6}\cdot G_7} = \begin{cases} \dfrac{G6\,((G3+G4)\,(G1\,(G2+G3)+1)+G5\,(G2+G3))}{G1\,(G2+G3)\,(G6\,G7\,(G3+G4)+G6+1)+G6\,G7\,(G5\,(G2+G3)+G3+G4)+G6+1} \\ \dfrac{G6\left(\frac{G5\,(G2+G3)}{G1\,(G2+G3)+1}+G3+G4\right)}{(G6+1)\left(\frac{G6\,G7\left(\frac{G5\,(G2+G3)}{G1\,(G2+G3)+1}+G3+G4\right)}{G6+1}+1\right)} \end{cases}$$

1) a) $E = \Omega_{ref} - \Omega_m = -\Omega_m$

$$\Omega_m = \frac{1}{Js+b}\left[d_t + \frac{10k_p}{0{,}5s+1}e\right] \qquad d_t = \frac{1}{s}$$

$$E = -\frac{1}{Js+b}d_t - \frac{10k_p}{(0{,}5s+1)(Js+b)}e \Leftrightarrow e\left(1+\frac{10k_p}{(0{,}5s+1)(Js+b)}\right) = -\frac{1}{Js+b}\cdot\frac{1}{s}$$

$$E = -\frac{\frac{1}{(Js+b)s}}{\frac{(0{,}5s+1)(Js+b)+10k_p}{(0{,}5s+1)(Js+b)}} = -\frac{0.5s+1}{[(0{,}5s+1)(Js+b)+10k_p]\,s}$$

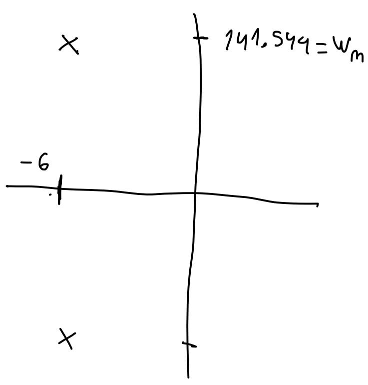
$$e(+\infty) = \lim_{s\to 0} E\cdot s = -\frac{1}{1+10k_p} \Rightarrow \left|-\frac{1}{1+10k_p}\right| \leq 0.001 \Leftrightarrow \frac{1000-1}{10} \leq k_p \Leftrightarrow 99.9 \leq k_p$$

b)

$$H(s) = \frac{\frac{10k_p}{(0.5s+1)(Js+b)}}{1+\frac{10k_p}{(0.5s+1)(Js+b)}} = \frac{10k_p}{10k_p+(0.5s+1)(0.1s+1)} = \frac{10k_p}{0.05s^2+0.6s+1+10k_p} = \frac{200k_p}{s^2+12s+20+200k_p}$$

$$w_n = \sqrt{20\,000} \qquad w_d = w_n\cdot\sqrt{1-\xi^2}$$

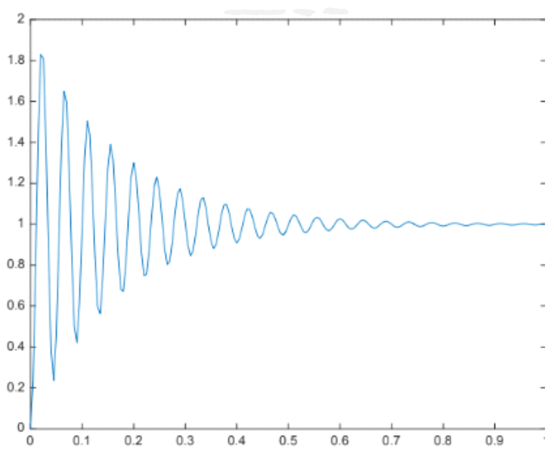
$$\xi = \frac{12}{2\cdot w_n}$$



$$t_s(2\%) = \frac{4}{\xi w_n} = 0.6667$$

$$S\% = 100\,e^{-\frac{\xi\pi}{\sqrt{1-\xi^2}}} = 87.5\%$$

Matlab

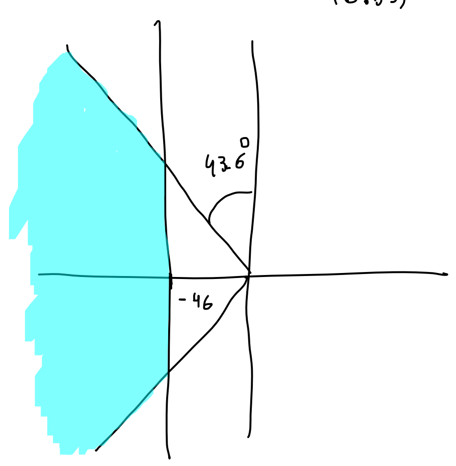


Não é satisfatório!

c) $t_s(1\%) \leq 0.1 \Leftrightarrow \frac{4.6}{\xi w_n} \leq 0.1 \Leftrightarrow 46 \leq \xi w_n$

$$S\% \leq 5\% \Rightarrow \xi \geq \sqrt{\frac{\ln^2(0.05)}{\pi^2+\ln^2(0.05)}} \Leftrightarrow \xi \geq 0.691$$

$$\theta \geq \arccos(\xi) \Leftrightarrow \theta \geq 43.6386^\circ$$



d) Escolher um valor possível para os polos: $46+46j$, $46-46j$

$$\frac{\Omega(s)}{\Omega_{ref}(s)} = \frac{200k_p(1+sT_D)}{s^2+12s+20+200k_p(1+sT_D)} = \frac{200k_p+200sT_Dk_p}{s^2+(12+200k_pT_D)s+20+200k_p}$$

$$\begin{cases} 20+200k_p = \omega^2 \\ 12+200k_pT_D = 2\xi\omega \end{cases} \Leftrightarrow \begin{cases} k_pT_D \approx 0.4 \\ k_p = 21.06 \\ T_D = 0.019 \end{cases}$$

Com $46+46j$

e) $k_p = 21.06 \Rightarrow e(t\to+\infty) = \left|\frac{-1}{10k_p+1}\right| = 0.00472$

Resolve-se colocando um integrador no controlador

12)

a)

$$\frac{Y(s)}{R(s)} = \frac{K_p \frac{s+1}{s-3}}{1 + K_p \frac{s+1}{s-3}} = \frac{K_p(s+1)}{(s-3)+(s+1)K_p} = \frac{K_p(s+1)}{s(1+K_p) - 3 + K_p}$$

$s = -\frac{K_p - 3}{K_p + 1}$ é estável se $K_p > 3$

$$E(s) = \frac{1}{1 + K_p \frac{s+1}{s-3}} \cdot R(s) = \frac{1}{1 + K_p \frac{s+1}{s-3}} \cdot \frac{C}{s}$$

$$e = \lim_{s \to 0} s \cdot E(s) = \frac{C}{1 - \frac{K_p}{3}}$$

b)

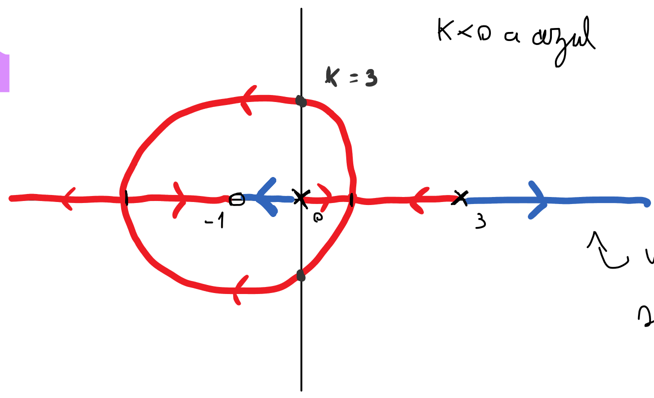
$$\frac{Y(s)}{R(s)} = \frac{K_p(s+1)}{s(1+K_p) - 3 + K_p}$$

$$\lim_{s \to 0} s \cdot \frac{1}{K_p} \cdot \frac{d}{s} \cdot \frac{K_p(s+1)}{s(1+K_p) - 3 + K_p} = \frac{1}{-3 + K_p} \cdot d$$

$$\frac{1}{-3 + K_p} < 0.1 \iff 1 < 0.1(-3 + K_p) \iff 13 < K_p$$

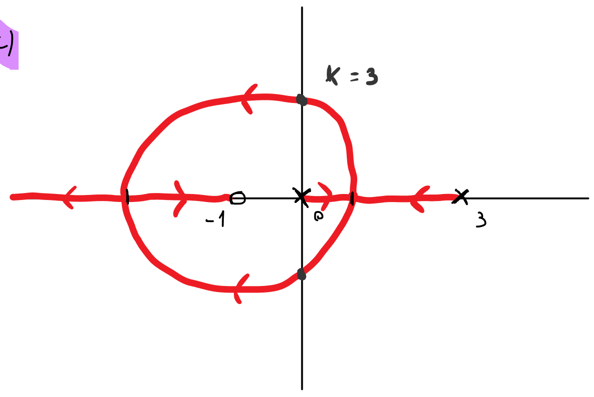
e)

K<0 a azul



↰ vão haver sempre polos no s.p.c.d. ⇒ vai ser instável

c)



$$1 + k \cdot \frac{1}{s} \cdot \frac{s+1}{s-3} = 0 \qquad n = 2 \quad m = 1$$

$$\hookrightarrow k = -\frac{s(s-3)}{s+1}$$

$$\frac{dk}{ds} = \frac{-s^2 + 2s - 3}{(s+1)^2}$$

$$-s^2 + 2s - 3 = 0 \iff \boxed{\begin{matrix} s = -3 \\ s = 1 \end{matrix}}$$ break in / break away ponto

$$\phi_a = 180°$$

d)

$$Y = \left(E \frac{k_1}{s} + D\right) \frac{s+1}{s-3}$$

$R - Y = E$

$$\Rightarrow Y = \left(-Y \frac{k_1}{s} + D\right) \frac{s+1}{s-3} \iff Y = -Y \cdot \frac{k_1}{s} \cdot \frac{s+1}{s-3} + D \frac{s+1}{s-3} \iff$$

$$Y = D \frac{\frac{s+1}{s-3}}{\left(1 + \frac{k_1}{s} \cdot \frac{s+1}{s-3}\right)}$$

$$Y(+\infty) = \lim_{s \to 0} s\, Y(s) = \lim_{s \to 0} s \cdot \frac{d}{s} \cdot \frac{\frac{s+1}{s-3}}{1 + \frac{k_1}{s} \cdot \frac{s+1}{s-3}} = 0$$

$$Z = E \frac{k_1}{s} = -Y \frac{k_1}{s} \qquad Z(+\infty) = \lim_{s \to 0} -s \cdot Y(s) \cdot \frac{k_1}{s} = -d$$

f)

$$Y = \left(E \frac{k_1}{s} + D\right) \frac{s+1}{s-3}$$

$R - K_m Y = E$

$$\hookrightarrow Y = (R - K_m Y) \frac{k_1}{s} \cdot \frac{s+1}{s-3}$$

$$Y = R \frac{k_1}{s} \cdot \frac{s+1}{s-3} - K_m Y \frac{s+1}{s-3} \cdot \frac{k_1}{s} \iff$$

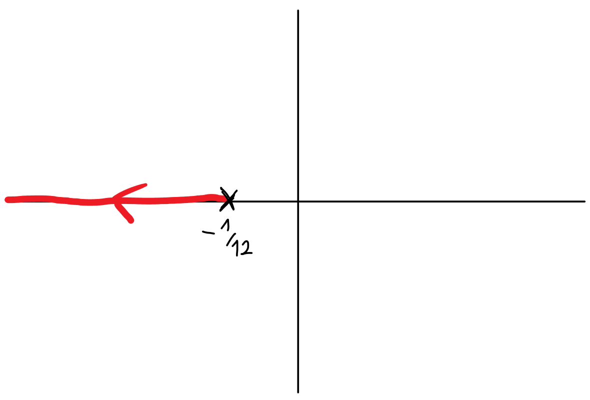
$$\iff Y = \frac{R \cdot \frac{k_1}{s} \cdot \frac{s+1}{s-3}}{1 + K_m \frac{s+1}{s-3} \cdot \frac{k_1}{s}} \qquad R = \frac{C}{s}$$

$$Y(+\infty) = \lim_{s \to 0} s \cdot Y(s) = \lim_{s \to 0} \frac{C \cdot \frac{k_1}{s} \cdot \frac{s+1}{s-3}}{1 + K_m \frac{s+1}{s-3} \cdot \frac{k_1}{s}} = \frac{C}{K_m}$$

8 f)

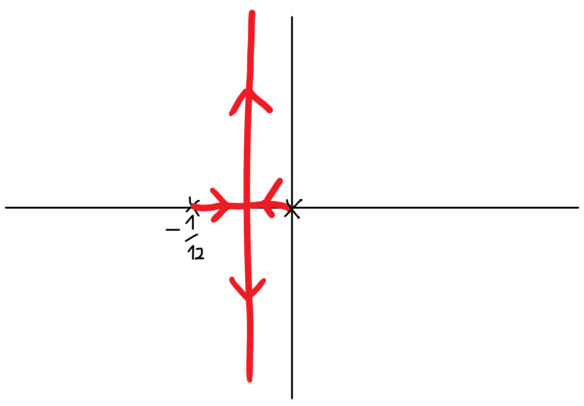
$$G(s) = \frac{1/2}{s + 1/12} \qquad K\,G(s)H(s) = K \frac{1/2}{s + 1/12}$$

$C = k$



$$G(s) = \frac{1/2}{s + 1/12} \qquad K\,G(s)\,H(s) = \frac{K\,1/2}{s(s + 1/12)}$$

$C = \frac{k}{s}$



$n = 2$ Ramos

$$K = -\frac{s(s + 1/12)}{1/2}$$

$$\frac{dK}{ds} = -2\left(2s + \frac{1}{12}\right) = -\frac{24s + 1}{6}$$

$$\phi_a = \frac{(2K+1)\pi}{n-m} \left\{ \begin{matrix} \frac{\pi}{2} \\ \frac{3\pi}{2} \end{matrix} \right.$$

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$$\frac{-24s + 1}{6} = 0 \iff \boxed{s = -\frac{1}{24}}$$