NOTA = 30

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10

① $s^3 + 5s^2 + 2s^2 + 10s = \boxed{s^3 + 7s^2 + 10s}$

a) $G(s) = \frac{K}{s^3 + 7s^2 + 10s} = \frac{K}{s(s^2 + 7s + 10)} = \boxed{\frac{K}{s(s+2)(s+5)}}$ Tipo $N = 1$

b) $K_v = \lim_{s \to 0} \left[\cancel{s} \cdot \frac{K}{\cancel{s}(s+5)(s+2)} \cdot \frac{1}{1} \right] = \frac{K}{5 \cdot 2} = \boxed{\frac{K}{10}} \Rightarrow K_v = \frac{10}{10} = 1$

$e_{ss} = \lim_{s \to 0} \left\{ s \left[\frac{1}{1+GH} \cdot \frac{0.1}{s^2} \right] \right\}$

$= \lim \left\{ \frac{0.1}{s + sGH} \right\}$

$= \frac{0.1}{K_v}$ *

c) $K_p = \lim_{s \to 0} \left[\frac{K}{s(s+2)(s+5)} \cdot \frac{1}{1} \right] = \frac{K}{0} = \boxed{\infty} \Rightarrow e_{ss} = \frac{1}{1 + K_p} = 0$

d) $K_v = \lim_{s \to 0} \left[\cancel{s} \cdot \frac{K}{\cancel{s}(s+2)(s+5)} \cdot \frac{1}{1} \right] = \boxed{\frac{K}{10}} \Rightarrow K_v = \frac{20}{10} = \boxed{2} \overset{*}{\Rightarrow} e_{ss} = \frac{0.1}{2} = 0.05 \ \frac{°C}{min}$

e) Para obter o menor valor de e_{ss}, o valor de K_v deve ser o maior possível dentro da estabilidade. Logo, para o maior valor de K_v, deve-se encontrar o maior valor de K, no qual o sistema continua estável.

FTMF: $F = \frac{G}{1 + GH} = \frac{K}{s^3 + 7s^2 + 10s + K}$.

$$\begin{array}{c|cc} s^3 & 1 & 10 \\ s^2 & 7 & K \\ s^1 & \frac{70-K}{7} & 0 \\ s^0 & K & 0 \end{array}$$

$\frac{70-K}{7}$

- $K > 0$
- $\frac{70-K}{7} > 0 \Rightarrow 70 - K > 0 \Rightarrow K < 70$

$\boxed{0 < K < 70}$

O maior valor de K é 70, para estabilidade.

$K_v = \lim_{s \to 0} \left[\cancel{s} \frac{K}{\cancel{s}(s+2)(s+5)} \cdot \frac{1}{1} \right] = \frac{K}{10} \Rightarrow K_v = \frac{70}{10} = \boxed{7}$

$e_{ss} \overset{*}{=} \frac{0.1}{7} = \frac{1}{70} \approx 0.014 \ \frac{°C}{min}$

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2

$$G = \frac{3}{s(0.5s+\sqrt{2})} \Rightarrow \begin{matrix} K=3 \\ a=\sqrt{2} \end{matrix} \Rightarrow \text{FTMF}: F_0 = \frac{6}{s^2+2\sqrt{2}s+6} \begin{cases} w_n = \sqrt{6} \\ \xi = \frac{2\sqrt{2}}{2\sqrt{6}} = \frac{\sqrt{3}}{3} \end{cases}$$

a)

$$M_p = e^{-\left(\frac{\xi\pi}{\sqrt{1-\xi^2}}\right)} = 0.10845 \Rightarrow \boxed{M_p = 10{,}85\%}$$

$$t_p = \frac{\pi}{w_n\sqrt{1-\xi^2}} = \frac{\pi}{\sqrt{6}\sqrt{1-\left(\frac{1}{\sqrt{3}}\right)^2}} = \frac{\pi}{2} \Rightarrow \boxed{t_p \cong 1{,}57\,s}$$

OBS.: O gráfico encontra-se na próxima página.

b)

$$G_1 = \frac{3K_p}{s(0.5s+\sqrt{2})} = \frac{6K_p}{s(s+2\sqrt{2})} \Rightarrow K_p' = 6K_p \Bigg\} F_1 = \frac{K_p'}{s^2+2\sqrt{2}s+K_p'} =$$

$$K_p' = \frac{(2\sqrt{2})^2\left\{\pi^2 + \ln\left(\frac{M_p}{2}\right)^2\right\}}{4\ln\left(\frac{M_p}{2}\right)^2} = 4{,}32 \Rightarrow K_p = \frac{K_p'}{6} = \boxed{0{,}72}$$

c) O gráfico encontra-se na próxima página.

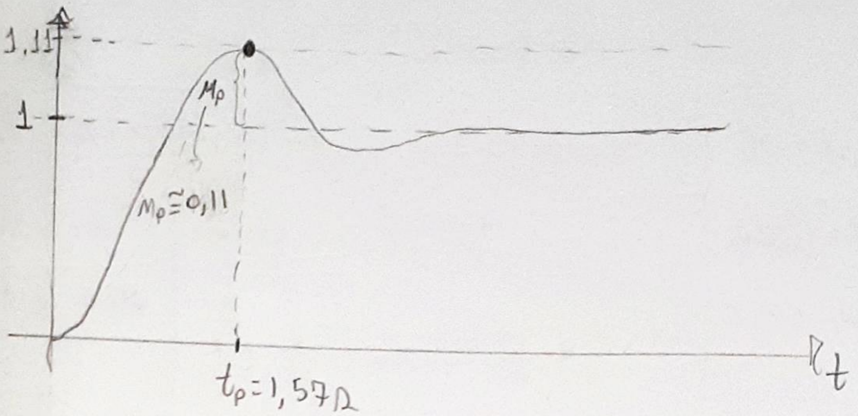
d)

$$F_2 = \frac{K_p'}{s^2+2\sqrt{2}s+K_p'}, \quad K_p' = 6K_p \Rightarrow K_p' = \frac{\pi^2}{\left(\frac{t_p}{2}\right)^2} + \frac{(2\sqrt{2})^2}{4} = 18 \Rightarrow K_p = \frac{18}{6} = \boxed{3}$$

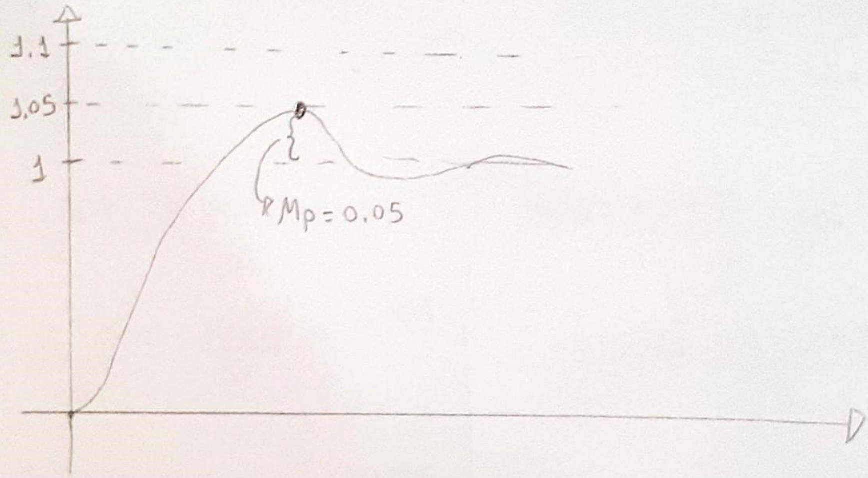
e) O gráfico se encontra na próxima página.

② Continuação

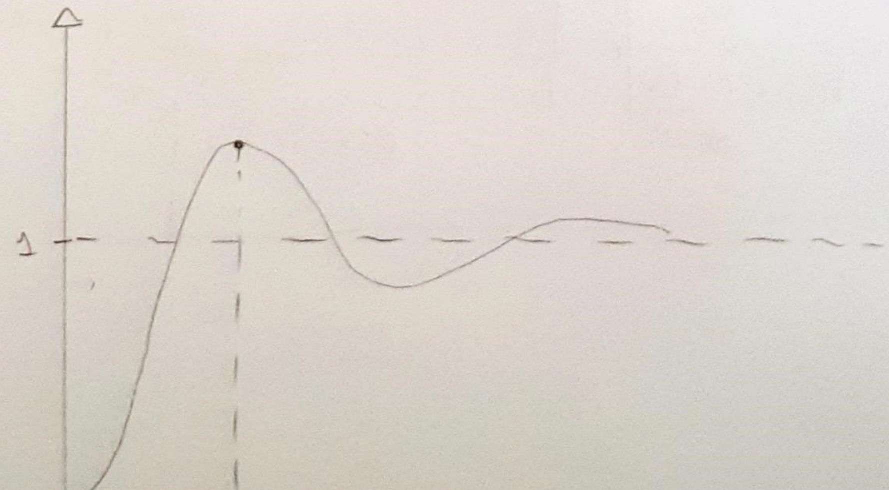
a)



c)



e)



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③ $G = \frac{0.5}{s(s^2+2.5s+1)}$; $K_D = 0$ $K_i = 0$ $\Rightarrow$ $G_p = \frac{0,5\,K_p}{s(s^2+2,5s+1)}$

$$\boxed{F = \frac{0.5K_p}{s^3+2.5s^2+s+0.5K_p}} \cdot \left\{ \frac{2.5-0.5K_p}{2.5} = 1 - \frac{K_p}{5} \right.$$

$$\begin{array}{c|cc} s^3 & 1 & 1 \\ s^2 & 2.5 & 0.5K_p \\ s^1 & 1-\frac{K_p}{5} & 0 \\ s^0 & \frac{K_p}{2} & 0 \end{array}$$

- $\frac{K_p}{2} > 0 \Rightarrow K_p > 0$
- $1 - \frac{K_p}{5} > 0 \Rightarrow 1 > \frac{K_p}{5} \Rightarrow 5 > K_p$

$\Rightarrow \boxed{0 < K_p < 5}$

$K_p = K_{cr} = 5$ e $s = j\omega_{cr}$

$(j\omega_{cr})^3 + 2.5(j\omega_{cr})^2 + (j\omega_{cr}) + 0.5 \times 5 = 0$

$2.5(1-\omega_{cr}^2) + (\omega_{cr} - \omega_{cr}^3)j = 0$

$\boxed{\omega_{cr} = 1}$ e $\cancel{\omega_{cr} = -1}$

$\omega = \frac{2\pi}{P_{cr}} \Rightarrow P_{cr} = \frac{2\pi}{1} = \boxed{2\pi} = 6,28$

$K_p = 0.6\,K_{cr} = 3$

$K_i = \frac{1,2\,K_{cr}}{P_{cr}} = \frac{1.2 \times 5}{2\pi} = 0.95$

$K_D = 0.075 \cdot P_{cr} K_{cr} = \frac{3\pi}{4} = 2,36$

$PID = K_p + \frac{K_i}{s} + K_D s$

$= \left(\frac{2,36s^2 + 3s + 0.95}{s}\right)$ ✓