Q_9: $\theta(s) = T(s)\left(R(s) + T_d(s) / G_c\right)$

$$\Rightarrow \theta(s) = \frac{\frac{K_pA}{\tau m}}{s^2 + \frac{1}{\tau m}\cdot s + \frac{K_pA}{\tau m}} \cdot R(s) + \frac{\frac{A}{\tau m}}{s^2 + \frac{1}{\tau m} s + \frac{kp}{\tau m}} \cdot T_d(s)$$

Q_{10}: $E(s) = R(s) - Y(s)$

$$= R(s) - R(s)\cdot T(s)$$

$$= R(s)\cdot\left[1 - \frac{G_c(s)\cdot G(s)}{1+G_c(s)\cdot G(s)}\right]$$

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

$\because R(s) = \frac{\theta d}{s}$

$$\therefore \Rightarrow \frac{\frac{\theta d}{s}}{1+G_c(s)\cdot G(s)}$$

$$e_{ss} = \lim_{t\to\infty} e(t) = \lim_{s\to 0} s\cdot \frac{\frac{\theta d}{s}}{1+G_c(s)G(s)} = \frac{\theta d}{1+G_c(0)\cdot G(0)}$$

$G_c(0) = kp$

$G(0) = \infty$

$\Rightarrow e_{ss} \approx 0$

Q.1 $E(s) = R(s) - Y(s)$

$$= R(s) - T(s)\left[R(s) + Td(s)/G_c\right]$$

$$= R(s)\cdot\left[1 - \frac{G_c(s)\cdot G(s)}{1+G_c(s)\cdot G(s)}\right] + \frac{G(s)}{1+G_c(s)\cdot G(s)}\cdot Td(s)$$

$$= \frac{R(s) + Td(s)\,G(s)}{1+G_c(s)\cdot G(s)}$$

$$= \frac{R(s) + Td(s)\frac{A}{s(\tau m s+1)}}{1+\frac{KpA}{s(\tau m s+1)}}$$

$$= \frac{R(s)\cdot s(\tau m s+1) + Td(s)\cdot A}{KpA}$$

$$ess = \lim_{s\to 0} s\cdot\frac{\frac{\theta d}{s}\cdot s(\tau m s+1) + Td(s)\cdot A}{KpA}$$

$$= \lim_{s\to 0}\frac{\theta d\cdot s\cdot(\tau m s+1) + Td\cdot A}{KpA} = \frac{Td}{Kp}$$

Q_{12}: $\theta(s) = T(s) \cdot \left[R(s) + \frac{T_d(s)}{k_p} - \frac{\theta(s) \cdot k_v s}{k_p} \right]$

$$\theta(s) = \frac{k_p G(s)}{1+G(s)k_p} \cdot R(s) + \frac{G(s)}{1+G(s)k_p} \cdot T_d(s) - \frac{G(s) \cdot \theta(s) \cdot k_v s}{1+G(s)k_p} \cdot \theta(s) +$$

$$\theta(s) \cdot \frac{G(s) k_v s}{1+G(s)k_p}$$

$$\theta(s) \frac{G(s)k_v s + 1 + G(s)k_p}{1+G(s)k_p} = \frac{k_p G(s)}{1+G(s)k_p} \cdot R(s) + \frac{G(s)}{1+G(s)k_p} \cdot T_d(s)$$

$$\theta(s) = \frac{k_p G(s)}{G(s)k_v s + G(s)k_p + 1} \cdot R(s) + \frac{G(s)}{G(s)k_v s + G(s)k_p + 1} \cdot T_d(s)$$

$$\Rightarrow = \frac{\frac{k_p A}{\tau m}}{s^2 + s \cdot \frac{k_v A + 1}{\tau m} + \frac{k_p A}{\tau m}} \cdot R(s) + \frac{\frac{A}{\tau m}}{s^2 + s \cdot \frac{k_v A + 1}{\tau m} + \frac{k_p A}{\tau m}} \cdot T_d(s)$$

Q_{13}: $E(s) = R(s) - \theta(s)$

$$= \left[1 - \frac{\frac{kpA}{\tau m}}{s^2 + \frac{1+kvA}{\tau m}s + \frac{kpA}{\tau m}}\right] \cdot R(s) - \frac{\frac{A}{\tau m}}{s^2 + s\frac{kvA+1}{\tau m} + \frac{kpA}{\tau m}} \cdot Td(s)$$

$$= \frac{\left(s^2 + \frac{1+kvA}{\tau m} \cdot s\right) R(s) - \frac{A}{\tau m} Td(s)}{s^2 + \frac{1+kvA}{\tau m} \cdot s + \frac{kpA}{\tau m}}$$

$$ess = \lim_{s \to 0} s \cdot \frac{\left(s^2 + \frac{1+kvA}{\tau m} \cdot s\right) R(s) - \frac{A}{\tau m} \cdot Td(s)}{s^2 + \frac{1+kvA}{\tau m} \cdot s + \frac{kpA}{\tau m}}$$

$$= - \frac{Td \cdot \frac{A}{\tau m}}{\frac{Akp}{\tau m}}$$

$$|ess| = \frac{Td}{kp}$$

Q_{14}: $\theta(s) = T(s) \cdot \left[R(s) + \frac{T_d(s)}{k_p} \right]$

$$\Rightarrow \quad T(s) = \frac{\frac{k_p A}{\tau_m}}{s^2 + \frac{1+k_v A}{\tau_m} s + \frac{k_p A}{\tau_m}}$$

$$\Rightarrow \quad \omega_n = \sqrt{\frac{k_p A}{\tau_m}}$$

$$2 \zeta \omega_n = \frac{1+k_v A}{\tau_m}$$

$$\zeta = \frac{1+k_v A}{2\tau_m} \cdot \frac{\sqrt{\tau_m}}{\sqrt{k_p A}}$$

$$\zeta = \frac{1+k_v A}{2\sqrt{k_p A \cdot \tau_m}}$$

Q15: $T_s = \frac{4}{\xi \omega_n} = \frac{4}{\frac{1+k_vA}{2\tau_m}} = \frac{8\tau_m}{1+k_vA}$

$$\text{percentage overshoot} = 100 \cdot \exp\left(-\frac{\pi\xi}{\sqrt{1-\xi^2}}\right)$$

$$= 100 \exp\left(-\frac{\pi \frac{1+k_vA}{2\sqrt{k_pA\cdot\tau_m}}}{\sqrt{1-\frac{(1+k_vA)^2}{4k_pA\cdot\tau_m}}}\right)$$

$$= 100 \exp\left(\frac{-\pi}{\sqrt{\frac{4k_pA\cdot\tau_m}{(1+k_vA)^2}-1}}\right)$$

$$T_{r_1} = \frac{2.16\xi + 0.6}{\omega_n} = \frac{2.16\cdot\frac{1+k_vA}{2\sqrt{k_pA\cdot\tau_m}}+0.6}{\sqrt{\frac{k_pA}{\tau_m}}}$$

$$= 2.16\frac{(1+k_vA)}{2k_pA} + 0.6\frac{\sqrt{\tau_m}}{\sqrt{k_pA}} = \frac{2.16(1+k_vA)+1.2\sqrt{k_pA\cdot\tau_m}}{2k_pA}$$

when k_p increases, the settling time will not affect, rise time decrease and maximum overshoot increase.

when k_v increases, the settling time decrease, rice time increase, and maximum overshoot decrease