

CLOSED-LOOP BLOCK-DIAGRAMS[1-5]

References:

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3. Seborg D.E., Mellichamp D. A., Edgar T.F, Doyle F.J., 2011, Process Dynamics and Control , John Wiley and Sons ISBN: 978-0-470-64610-6
4. Seborg D.E., Mellichamp D. A., Edgar T.F, Doyle F.J., ÇEVİRENLER: Tapan N.A., Erdoğan S. 3. baskıdan çeviriden 1.basım, 2012, Proses Dinamiği ve Kontrolü, Nobel Akademik Yayıncılık ISBN: 978-605-133-298-7
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$$\theta_1(s) = X(s) - Y(s)$$

$$\theta_2(s) = \theta_1(s) - \theta_3(s)$$

$$\theta_3(s) = \theta_2(s) * G_1(s)$$

$$Y(s) = \theta_3(s) * G_2(s) \quad \theta_3(s) = \frac{Y(s)}{G_2(s)}$$

$$Y(s) = \theta_2(s) * G_1(s) * G_2(s)$$

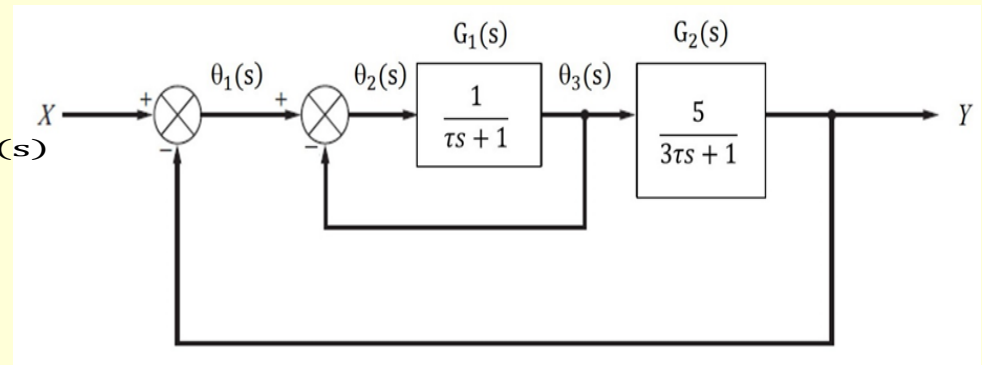
$$Y(s) = (\theta_1(s) - \theta_3(s)) * G_1(s) * G_2(s)$$

$$Y(s) = \left[X(s) - Y(s) - \frac{Y(s)}{G_2(s)} \right] * G_1(s) * G_2(s)$$

$$Y(s) = G_1 G_2 X(s) - G_1 G_2 Y(s) - G_1 Y(s)$$

$$Y(s) [1 + G_1 G_2 + G_1] = G_1 G_2 X(s)$$

$$\frac{Y(s)}{X(s)} = \frac{G_1 G_2}{1 + G_1 G_2 + G_1}$$

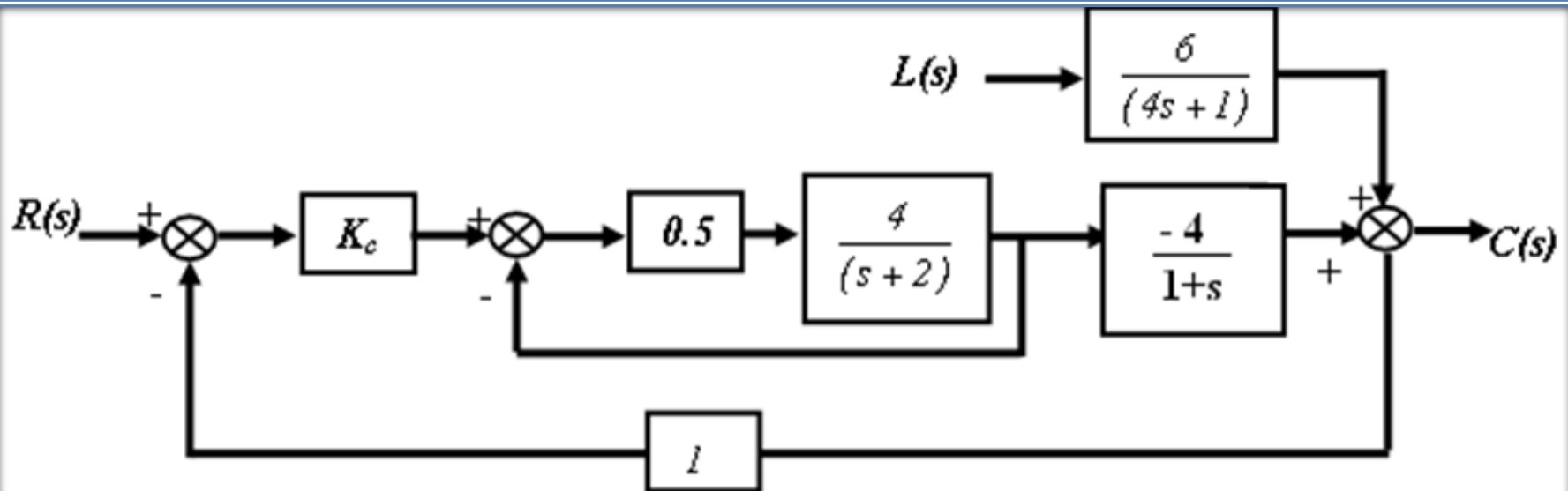


$$\frac{Y(s)}{X(s)} = \frac{\left(\frac{1}{\tau s + 1}\right) \left(\frac{5}{3\tau s + 1}\right)}{1 + \left(\frac{1}{\tau s + 1}\right) \left(\frac{5}{3\tau s + 1}\right) + \left(\frac{1}{\tau s + 1}\right)}$$

$$\frac{Y(s)}{X(s)} = \frac{\left(\frac{1}{\tau s + 1}\right) \left(\frac{5}{3\tau s + 1}\right)}{\frac{(\tau s + 1)(3\tau s + 1) + 5 + (\tau s + 1)}{(\tau s + 1)(3\tau s + 1)}} = \frac{5}{(\tau s + 1)(3\tau s + 1) + 5 + (\tau s + 1)}$$

$$\frac{Y(s)}{X(s)} = \frac{5}{3\tau^2 s^2 + 7\tau s + 7}$$

the feedback control system



$$C(s) = \frac{Kc \left(\frac{G_1 G_2}{1 + G_1 G_2} \right) G_3}{1 + Kc \left(\frac{G_1 G_2}{1 + G_1 G_2} \right) G_3 \cdot G_5} R(s) + \frac{G_4}{1 + Kc \left(\frac{G_1 G_2}{1 + G_1 G_2} \right) G_3 \cdot G_5} L(s)$$

$$G_1 = 0.5 \quad G_2 = \frac{4}{(s+2)} \quad G_3 = \frac{-4}{(1+s)} \quad G_4 = \frac{6}{(4s+1)} \quad G_5 = \frac{1}{8}$$

$$1 + Kc \left(\frac{G_1 G_2}{1 + G_1 G_2} \right) G_3 \cdot G_5 = 0 \quad \Rightarrow \quad 1 + Kc \left(\frac{0.5 * \frac{4}{(s+2)}}{1 + 0.5 * \frac{4}{(s+2)}} \right) * \left(\frac{-4}{(1+s)} \right) * \left(\frac{1}{8} \right) = 0$$

$$1 + Kc * \left(\frac{2}{(s+4)} \right) * \left(\frac{-4}{(1+s)} \right) * \left(\frac{1}{8} \right) = 0 \quad \Rightarrow \quad 1 - \frac{Kc}{(s+4)(1+s)} = 0$$

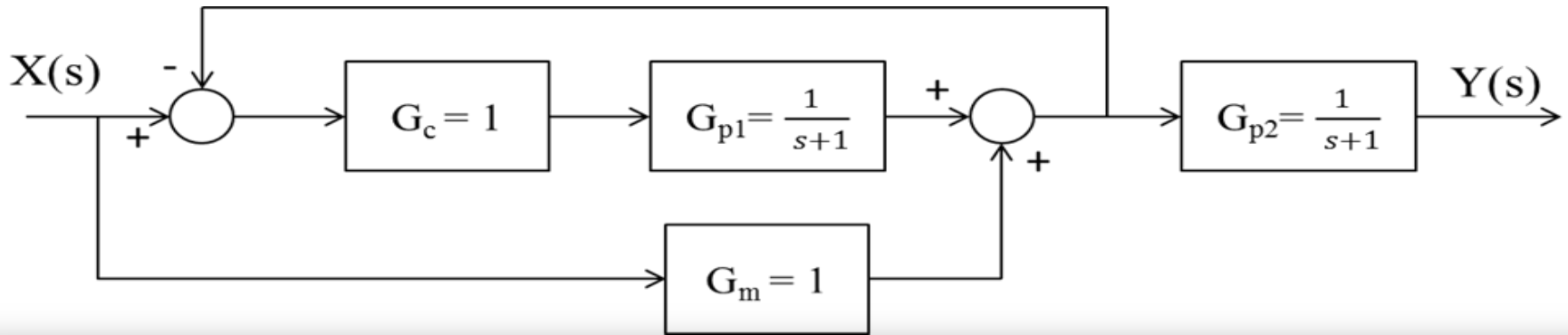
$$(s+4)(s+1) - Kc = 0 \quad \Rightarrow \quad s^2 + 5s + 4 - Kc = 0$$

$$\Delta = b^2 - 4ac = 5^2 - 4 \cdot 1 \cdot (4 - Kc)$$

$$s_{1,2} = \frac{-b \mp \sqrt{\Delta}}{2a} = \frac{-5 \mp \sqrt{25 - 4 * (4 - Kc)}}{2} = \frac{-5 \mp \sqrt{9 + 4Kc}}{2} \quad \Rightarrow \quad -2.5 \mp \frac{\sqrt{9 + 4Kc}}{2} < 0$$

$$\frac{\sqrt{9 + 4Kc}}{2} < 2.5 \quad \Rightarrow \quad \sqrt{9 + 4Kc} < 5 \quad \Rightarrow \quad 9 + 4Kc < 25 \quad \Rightarrow \quad 4Kc < 16 \quad \Rightarrow \quad Kc < 4$$

$$s^2 + 5s + 4 - Kc = 0 \quad \Rightarrow \quad 4 - Kc > 0 \quad \Rightarrow \quad Kc < 4$$



$$\frac{Y(s)}{X(s)} = \frac{G_{p2}(1 + G_c G_{p1})}{1 + G_c G_{p1}} = \frac{\frac{1}{s+1} \left(1 + 1 \times \frac{1}{s+1}\right)}{1 + 1 \times \frac{1}{s+1}} = \frac{1}{s+1}$$

$$X(s) = \frac{1}{s} \rightarrow Y(s) = \frac{1}{s(s+1)}$$

$$Y(\infty) = \lim_{s \rightarrow 0} sY(s) = 1$$

$$X(\infty) = 1 \rightarrow X(\infty) - Y(\infty) = 1 - 1 = 0$$

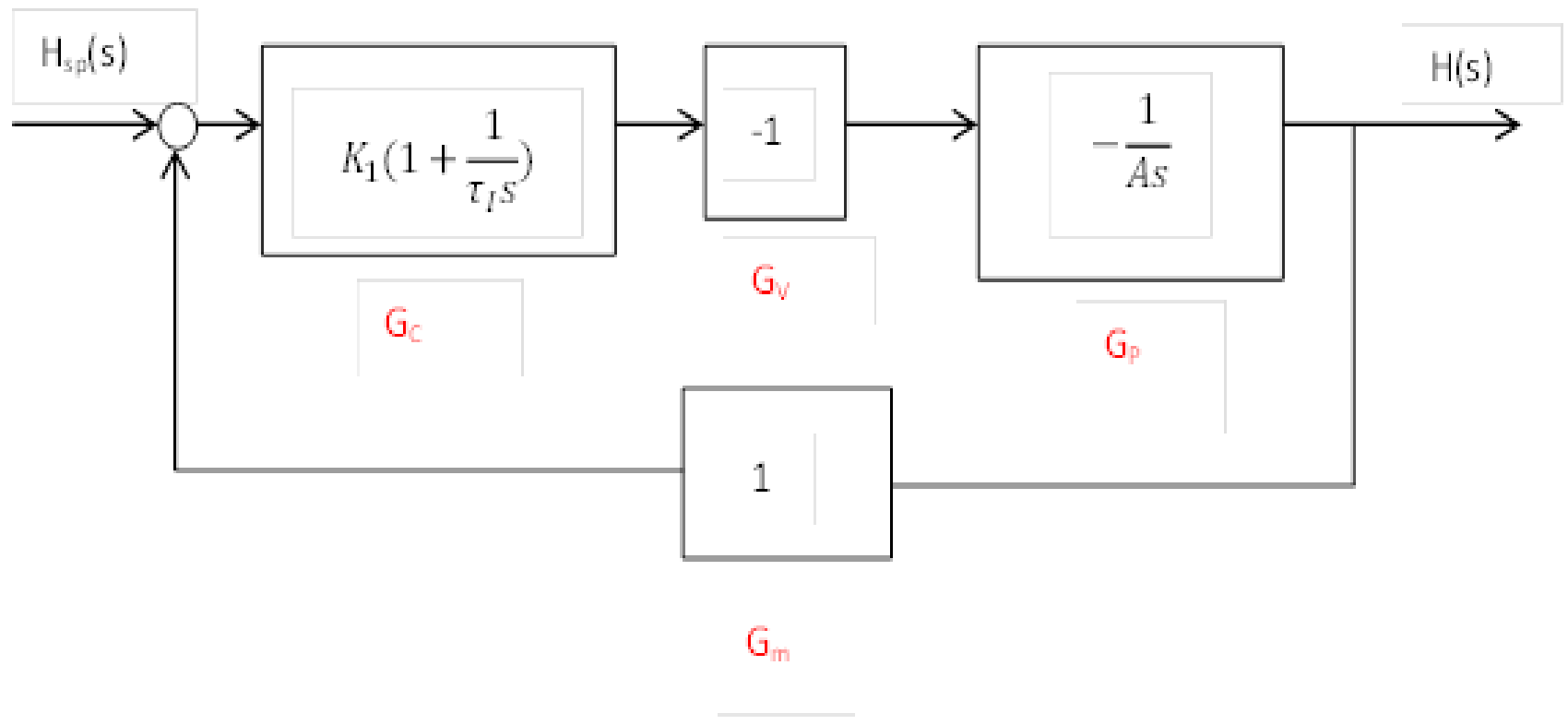
Unsteady state: $q_1 + q_2 - q_3 = A \frac{dh}{dt}$

Steady state: $q_1^0 + q_2^0 - q_3^0 = 0$ ($q_1 = q_1^0, q_2 = q_2^0$)

Unsteady state - Steady state: $-(q_3 - q_3^0) = A \frac{d(h - h_0)}{dt}$ ($Q_3 = q_3 - q_3^0, H = h - h_0$)

$-Q_3 = A \frac{dH}{dt}$

Taking Laplace transform, we get; $-Q_3(s) = A[sH(s) - H(0)] \rightarrow \frac{H(s)}{Q_3(s)} = -\frac{1}{As}$



$$\frac{H(s)}{H_{sp}(s)} = \frac{G_c G_v G_p}{1 + G_c G_v G_p G_m}$$

$$\frac{H(s)}{H_{sp}(s)} = \frac{K_1(1 + \frac{1}{\tau_I s})(\frac{1}{As})}{1 + K_1(1 + \frac{1}{\tau_I s}) * (-1) * (-\frac{1}{As}) * 1} = \frac{\frac{K_1}{As} + \frac{K_1}{\tau_I As^2}}{1 + \frac{K_1}{As} + \frac{K_1}{\tau_I As^2}}$$

$$\frac{H(s)}{H_{sp}(s)} = \frac{K_1(\tau_I s + 1)}{\tau_I As^2 + K_1 \tau_I s + K_1}$$

$$s_{1,2} = \frac{-\tau_I K_1 \pm \sqrt{\tau_I^2 K_1^2 - 4\tau_I A K_1}}{2\tau_I A}$$

$s_{1,2} < 0$ stable

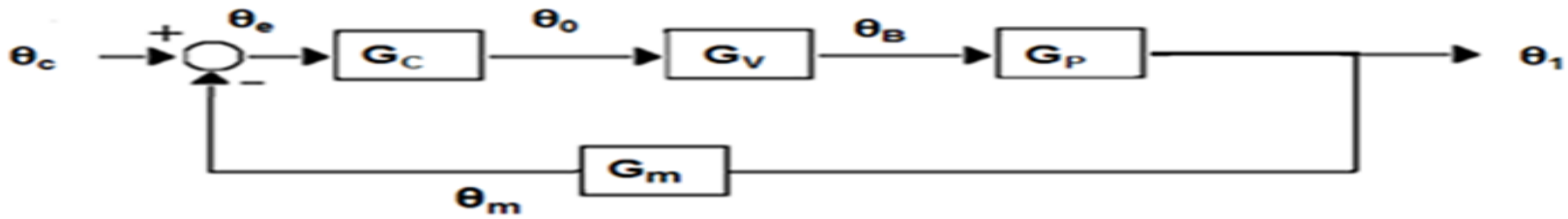
Dividing numerator and denominator by (K_1) ;

$$\frac{H(s)}{H_{sp}(s)} = \frac{(\tau_I s + 1)}{\left(\frac{\tau_I A}{K_1}\right) s^2 + \tau_I s + 1}$$

$$\text{c) } H_{sp}(s) = \frac{1}{s} \Rightarrow H(s) = \frac{(\tau_I s + 1) + 1}{\left(\frac{\tau_I A}{K_1}\right) s^2 + \tau_I s} * \frac{1}{s}$$

$$t \rightarrow \infty \quad H(t) = \lim_{s \rightarrow 0} [s H(s)] = \lim_{s \rightarrow 0} \left[\frac{s(\tau_I s + 1)}{\left(\frac{\tau_I A}{K_1}\right) s^2 + \tau_I s + 1} * \frac{1}{s} \right]$$

$$t \rightarrow \infty \quad H(t) = 1$$



$$\theta_e = \theta_c - \theta_m$$

$$\theta_0 = \theta_e G_c = [\theta_c - \theta_m] G_c$$

$$\theta_B = \theta_0 G_v = [\theta_c - \theta_m] G_c G_v$$

$$\theta_m = \theta_1 G_m$$

$$\theta_1 = \theta_B G_p = [\theta_c - \theta_m] G_c G_v G_p$$

$$\theta_1 = [\theta_c - \theta_1 G_m] G_c G_v G_p$$

$$\theta_1 = \theta_c G_c G_v G_p - \theta_1 G_m G_c G_v G_p$$

$$\theta_1 [1 + G_m G_c G_v G_p] = \theta_c [G_c G_v G_p]$$

$$\frac{\theta_1}{\theta_c} = \frac{G_c G_v G_p}{1 + G_m G_c G_v G_p}$$

$$\theta_1(s) = \frac{\left[k_1 \left(1 + \frac{1}{\tau_I s} \right) \right] G_v G_p}{1 + G_m \left[k_1 \left(1 + \frac{1}{\tau_I s} \right) \right] G_v G_p} \theta_c(s)$$

$$\theta_1(s) = \frac{\left[5 \left(1 + \frac{1}{4s}\right)\right] * 5 * \frac{4}{3s+9}}{1 + 4 \left[5 \left(1 + \frac{1}{4s}\right)\right] * 5 * \frac{4}{3s+9}} \theta_c(s)$$

$$\theta_1(s) = \frac{\frac{4s+1}{4s} * \frac{100}{3s+9}}{1 + \frac{4s+1}{4s} * \frac{400}{3s+9}} \theta_c(s)$$

$$\theta_1(s) = \frac{100(4s+1)}{(3s+9)(4s+1) + 400(4s+1)} \theta_c(s)$$

$$\theta_1(s) = \frac{400s+100}{12s^2+1636s+400} \theta_c(s)$$

$$\theta_1(s) = \frac{(400s+100)/12}{\left(\frac{12s^2}{12}\right) + \left(\frac{1636s}{12}\right) + \left(\frac{400}{12}\right)} * \frac{1}{s} = \frac{33.3333s+8.3333}{s^2+136.3333s+33.3333} * \frac{1}{s}$$

$$\theta_1(s) = \frac{33.3333s+8.3333}{(s+136.0884)(s+0.2449)} * \frac{1}{s} = \frac{A}{s} + \frac{B}{(s+136.0884)} + \frac{C}{(s+0.2449)}$$

$$A = \left[\frac{33.3333s + 8.3333}{s(s + 136.0884)(s + 0.2449)} * s \right]$$

$$A = 0.25$$

$$B = \left[\frac{33.3333s + 8.3333}{s(s + 136.0884)(s + 0.2449)} * (s + 136.0884) \right]$$

$$B = -0.2449$$

$$B = \left[\frac{33.3333s + 8.3333}{s(s + 136.0884)(s + 0.2449)} * (s + 0.2449) \right]$$

$$C = -0.0051$$

$$\theta_1(s) = \frac{0.25}{s} - \frac{0.2449}{(s + 136.0884)} - \frac{0.0051}{(s + 0.2449)}$$

$$\theta_1(s) = 0.25 - 0.2449e^{-136.0884t} - 0.0051e^{-0.2449t}$$