$$\frac{H_2(s)}{G_3(s)}$$

$$\frac{H_2(s)}{G_3(s)}$$

$U(s)$

$$\frac{G_1(s)G_2(s)G_3(s)}{}$$

$Y(s)$

$$\frac{H_2(s)}{G_3(s)}$$

$$U(s)$$

$$\frac{G_1(s)G_2(s)G_3(s)}{1 + G_2(s)G_3(s)H_1(s)}$$

$$Y(s)$$

$$U(s)$$

$$\frac{G_1(s)G_2(s)G_3(s)}{1 + G_2(s)G_3(s)H_1(s) + G_1(s)G_2(s)H_2(s)}$$

$$Y(s)$$

U(s) $G_1(s)$ $G_2(s)$ $G_3(s)$ Y(s) $H_2(s)$ $H_1(s)$

U(s) $G_1(s)$ $G_2(s)$ $G_3(s)$ Y(s) $\dfrac{H_2(s)}{G_3(s)}$ $H_1(s)$

U(s) $G_1(s)$ $\dfrac{G_2(s)G_3(s)}{1+G_2(s)G_3(s)H_1(s)}$ Y(s) $\dfrac{H_2(s)}{G_3(s)}$

U(s) $\dfrac{G_1(s)G_2(s)G_3(s)}{1+G_2(s)G_3(s)H_1(s)}$ Y(s) $\dfrac{H_2(s)}{G_3(s)}$

U(s) $\dfrac{G_1(s)G_2(s)G_3(s)}{1+G_2(s)G_3(s)H_1(s)+G_1(s)G_2(s)H_2(s)}$ Y(s)

I_a

R_a

L_a

I_f

L_f

R_f

J_{load}

$+$

V_a

$-$

e_b

$+$

$-$

τ

β

ω

$$V_a(s)$$

$$\frac{1}{L_a s + R_a} \qquad K_a \qquad \qquad \frac{1}{Js^2 + \beta s + \kappa} \qquad \qquad \Theta(s)$$

$$\mathcal{T}(s)$$

$$E_b(s) \qquad \qquad K_b s$$

$V_a(s)$

$$\frac{K_a}{JL_a s^3 + (JR_a + L_a\beta)s^2 + (L_a\kappa + \beta R_a + K_a K_b)s + R_a\kappa}$$

$\Theta(s)$

$$R_a \quad L_a$$

$$I_a$$

$$J_R$$

$$J_1$$
$$N_1 = 1$$

$$\omega_1$$

$$\tau$$

$$I_f$$

$$L_f$$

$$\times$$

$$\beta$$

$$\theta_2$$

$$R_f$$

$$\omega_2$$

Encoder

$$V_c$$

$$\theta_2$$

$$J_2$$

$$N_2 = n$$

$$V_c = \gamma \left(\theta^* - \theta_2 \right)$$

$$\theta^*$$

R_a

L_a

I_a

J_R

J_1

$N_1 = 1$

ω_1

τ

β

I_f

L_f

R_f

$\times$

Encoder

θ_2

θ_2

ω_2

J_2

$N_2 = n$

V_c

$+$

$-$

θ^*

$V_c = \gamma \left(\theta^* - \theta_2 \right)$

The upper diagram shows a DC motor circuit with armature (R_a, L_a, I_a) and field winding (L_f, R_f, I_f), connected to a mechanical shaft system with rotational inertia J_R, damping β, torque τ, and gears J_1 ($N_1 = 1$, ω_1) and J_2 ($N_2 = n$, ω_2). An encoder measures θ_2. The control voltage is:

$$V_c = \gamma\left(\theta^* - \theta_2\right)$$

The lower block diagram shows the closed-loop control system:

$$\Theta^*(s) \longrightarrow \boxed{\gamma} \longrightarrow \boxed{\frac{K_f}{L_f s + R_f}} \longrightarrow \boxed{\frac{n}{J_T s^2 + \beta_T s}} \longrightarrow \Theta_2(s)$$