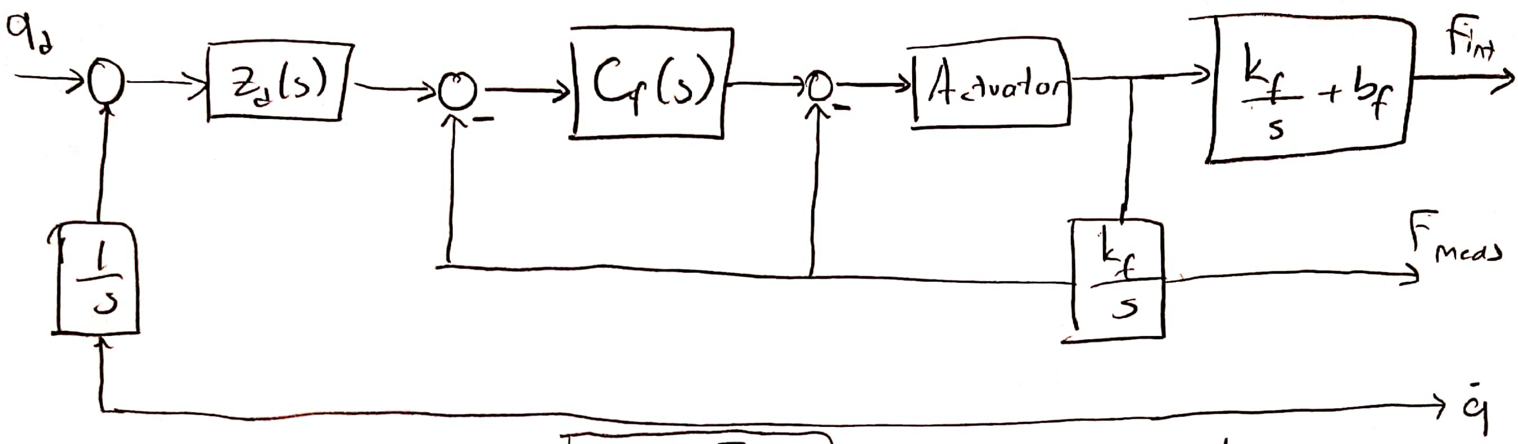

$$\dot{q} = qs \qquad \boxed{Z_e = \frac{F_{int}}{-\dot{q}}} \qquad \text{Actuator} = \frac{1}{J_m s + b_m}$$

$$C_f(s) = P + D\frac{s\tau}{s+\tau} \qquad Z_d(s) = k_d + d_d \frac{s\tau}{s+\tau}$$

$$F_{meas} = \frac{k_f}{s}\dot{q} \qquad F_{int} = \left(\frac{k_f}{s} + b_f\right)\dot{q}$$

$$T_{act} = \left(\frac{k_f}{s} + b_f\right) \qquad T_{sea} = \frac{k_f}{s}$$

$$\text{error} = q_d - q$$

$$F_{int} = \left(\left(\left(Z_d(s)\,\text{err} - F_{meas}\right) C_f - F_{meas}\right) \text{Actuator}\right) T_{act}$$

set $q_d = 0$, $q = \frac{\dot{q}}{s}$

$$F_{int} = \left(\left(\left(-\frac{Z_d(s)\dot{q}}{s} - \frac{k_f \dot{q}}{s}\right) C_f - \frac{k_f \dot{q}}{s}\right) \frac{1}{J_m s + b_m}\right)\left(\frac{k_f}{s} + b_f\right)$$

$$= \left(-\frac{Z_d(s)\dot{q}C_f}{s} - \frac{k_f \dot{q} C_f}{s} - \frac{k_f \dot{q}}{s}\right) Act\Big)\left(\frac{k_f}{s} + b_f\right)$$

$$F_{int} = -\dot{q}\left(\frac{Z_d(s)C_f + k_f C_f + k_f}{s}\right) Act \left(\frac{k_f}{s} + b_f\right)$$

$$err = q_d - q$$

$$\Big(\big((Z_d(s)\, err - F_{meas}) C_f - F_{meas}\big) Actuator\Big) T_{actual} = F_{int}$$

$$F_{meas} = \frac{k_f}{s} \dot{q} \qquad Z_d(s) = k_d + \frac{d_d s \tau}{s+\tau}$$

$$F_{int} = \left(\frac{k_f}{s} + b_f\right) \dot{q} \qquad C_f(s) = P + \frac{D s \tau}{s + \tau}$$

$$actuator = \frac{1}{J_m s + b_m} \qquad T_{actual\ sensing} = \left(\frac{k_f}{s} + b_f\right)$$

set $q_d = 0$, $q = \frac{\dot{q}}{s}$

$$F_{int} = \left(\left(\left(-Z_d(s) \frac{\dot{q}}{s} - \frac{k_f \dot{q}}{s}\right) C_f - \frac{k_f \dot{q}}{s}\right) \frac{1}{J_m s + b_m}\right)\left(\frac{k_f}{s} + b_f\right)$$

$$= \left(-\frac{Z_d \dot{q}}{s} C_f - \frac{k_f \dot{q}}{s} C_f - \frac{k_f \dot{q}}{s}\right) Act\Big)\left(\frac{k_f}{s} + b_f\right)$$

$$= \dot{q}\left(\frac{-Z_d C_f - k_f (C_f + 1)}{s}\right) Act \left(\frac{k_f}{s} + b_f\right)$$

$$Z_e = \frac{F_{int}}{-\dot{q}} = \frac{(+Z_d C_f + k_f (C_f + 1))\left(\frac{k_f}{s} + b_f\right)}{J_m s^2 + b_m s}$$

$$= \frac{(k_f + b_f s)(Z_d C_f + k_f (C_f + 1))}{J_m s^3 + b_m s^2}$$

$$= \frac{(k_f + b_f s)\left(\frac{k_d(s+\tau) + d_d s \tau}{s+\tau} \cdot \frac{P(s+\tau) + D s \tau}{s+\tau} + k_f\left(\frac{(P+1)s + \tau + D s \tau}{s+\tau}\right)\right)}{J_m s^3 + b_m s^2}$$

Case 1

$d_d \rightarrow 0$

Case 1.2

$b_m \rightarrow 0$

Case 2

$D \rightarrow 0$

Case 2.2

$b_m \rightarrow 0$

case 0

$b_m \rightarrow 0$

case 3

$D \Rightarrow 0$ $d_d \rightarrow 0$

case 3.1

$b_m \rightarrow 0$

$$Z_e = \frac{F_{int}}{-\dot{q}} = \frac{(k_f + b_f s)}{J_m s^3 + b_m s^2} \cdot \left(\frac{(k_d(s+T) + d_d s T)(P(s+T) + D s T) + k_f (s+T)((P+I)(s+T) + D s T)}{(s+T)^2} \right)$$