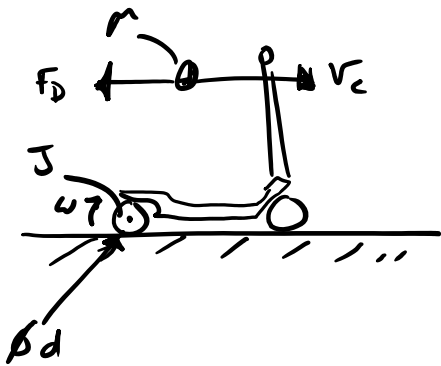


$$\textcircled{1} \quad \dot{q}_4 = \frac{(S_{e1} - \frac{z_4}{c_4})}{R_2} - \frac{p_7}{I_7}$$

$$\textcircled{3} \quad \dot{p}_7 = \frac{z_4}{c_4} - R_c \frac{p_7}{I_7} - \frac{q_8}{c_8}$$

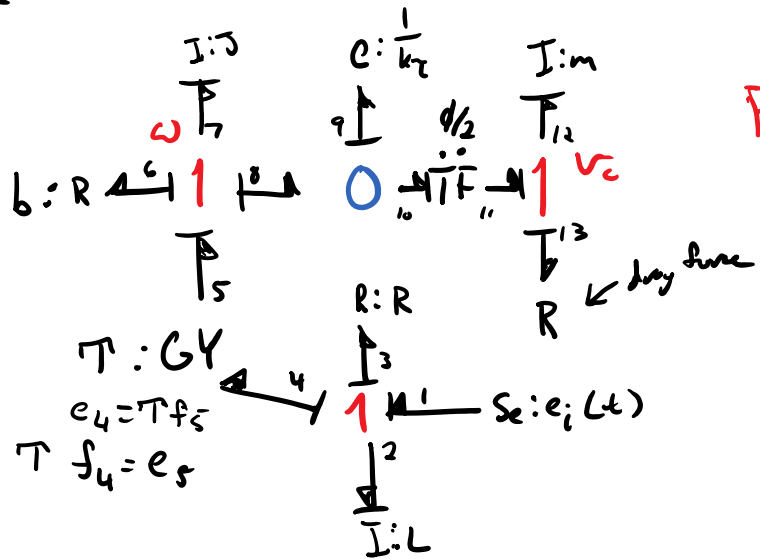
$$\textcircled{2} \quad \dot{q}_8 = \frac{p_7}{I_7}$$

Electric Jump Scooter



Input: S_c

States: P_2, P_7, l_9, P_{12}



$$P_{12} = T_{12} v_c$$

$$F_D = \frac{1}{2} C_D A \rho v_c^2$$

- ① $\dot{P}_2 = e_2 = e_1 - e_3 - e_4 = S_c(t) - R_3 f_3 - T f_5 = S_c(t) - R_3 \frac{P_2}{I_3} - T \frac{P_7}{I_7}$
- ② $\dot{P}_7 = e_7 = e_5 - e_6 - e_8 = T f_4 - R_6 f_6 - \frac{q_9}{C_9} = T \frac{P_2}{I_2} - R_6 \frac{P_7}{I_7} - \frac{q_9}{C_9}$
- ③ $\dot{q}_9 = f_9 = f_8 - f_{10} = \frac{P_7}{I_7} - \frac{2}{d} f_{11} = \frac{P_7}{I_7} - \frac{2}{d} \frac{P_{12}}{I_{12}}$
- ④ $\dot{P}_{12} = e_{12} = e_{11} - e_{13} = \frac{2}{d} e_{10} - \frac{1}{2} C_D A \rho \left(\frac{P_{12}}{I_{12}} \right)^2$

$$\dot{P}_{12} = \frac{2}{d} \frac{q_9}{C_9} - \frac{1}{2} C_D A \rho \left(\frac{P_{12}}{I_{12}} \right)^2$$

$$\dot{\bar{x}} = A \bar{x} + B \bar{u}$$

$b_0 v_c \leftarrow$ linear version

$$b_0 \frac{P_{12}}{I_{12}}$$

$$A_{4 \times 4}$$

$$4 \times 1$$

$$\dot{\bar{x}}$$

$$\begin{bmatrix} e_1 & T & \dots & \dots \end{bmatrix} \begin{bmatrix} P_7 & \dots \end{bmatrix} \begin{bmatrix} \dots \end{bmatrix}$$

$$\begin{bmatrix} -\frac{R_3}{I_2} & -\frac{T}{I_7} & 0 & 0 \\ \frac{T}{I_2} & -\frac{R_6}{I_7} & -\frac{1}{C_9} & 0 \\ 0 & \frac{1}{I_7} & 0 & -\frac{2}{dI_{12}} \\ 0 & 0 & \frac{2}{dC_9} & -\frac{b_p}{I_{12}} \end{bmatrix} \begin{bmatrix} P_2 \\ P_7 \\ q_9 \\ P_{12} \end{bmatrix} + \begin{bmatrix} 1 \\ 0 \\ 0 \\ 0 \end{bmatrix} [S_{e_1}(t)] = \begin{bmatrix} \dot{P}_2 \\ \dot{P}_7 \\ \dot{q}_9 \\ \dot{P}_{12} \end{bmatrix}$$

Outputs

$$\bar{y} = C\bar{x} + D\bar{u} \quad \dot{P}_2 = \frac{e_2}{f_2} \Sigma L$$

$$Li = P_2$$

$$\bar{y} = C\bar{x}$$

$$\begin{matrix} 4 \times 1 & & 4 \times 4 & & 4 \times 1 \\ \begin{bmatrix} i \\ \omega \\ \Delta\theta \\ v_c \end{bmatrix} & = & \begin{bmatrix} \frac{1}{I} & 0 & 0 & 0 \\ 0 & \frac{1}{J} & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & \frac{1}{m} \end{bmatrix} & \begin{bmatrix} P_2 \\ P_7 \\ q_9 \\ P_{12} \end{bmatrix} \end{matrix}$$

↑
output variables

$$q_9 = \Delta\theta$$

$$V_2 = V_1 + \omega R$$

$$\bar{v} = C \bar{x} \quad [V_2] = [1 \quad R] \begin{bmatrix} V_1 \\ \omega \end{bmatrix}$$

$$\begin{aligned} \dot{\bar{x}} &= A\bar{x} + B\bar{u} \\ \bar{y} &= C\bar{x} + D\bar{u} \end{aligned} \quad \left. \vphantom{\begin{aligned} \dot{\bar{x}} &= A\bar{x} + B\bar{u} \\ \bar{y} &= C\bar{x} + D\bar{u} \end{aligned}} \right\} \begin{array}{l} \text{full} \\ \text{state space} \\ \text{form} \end{array}$$

output equation

$$\bar{u} = [e_i(t)]$$

$$\begin{aligned} & \Sigma: e_i \xrightarrow{TF} e_2 \\ & e_i = me_2 \end{aligned}$$

$$D_{1,1} = \frac{1}{m}$$

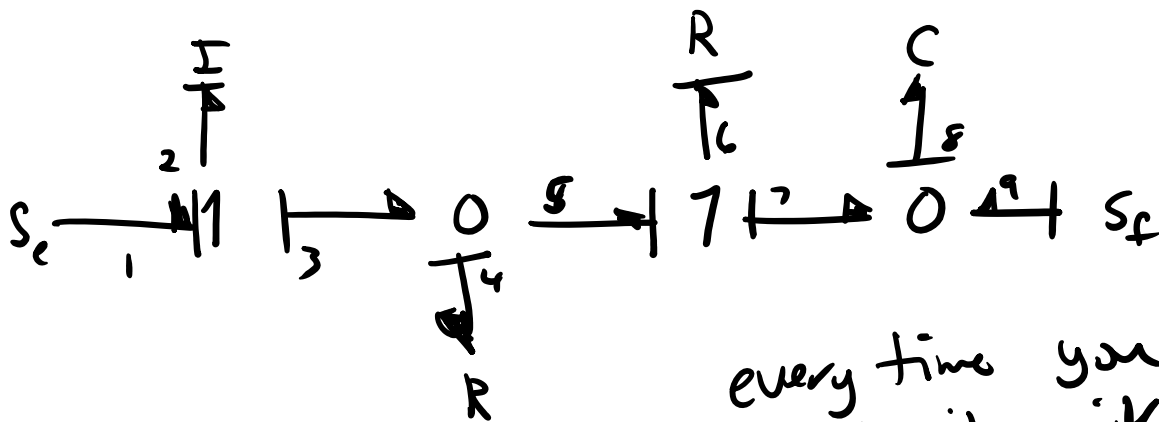
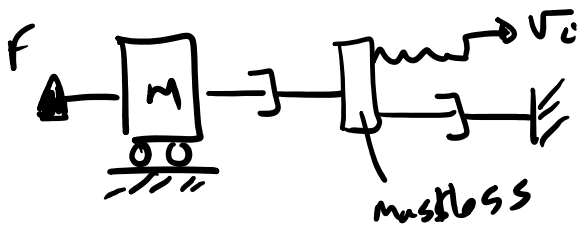
$$[e_2] = \bar{y} = \begin{matrix} D_{1 \times 1} & u \\ \left[\frac{1}{m} \right] & [e_i] \end{matrix}$$

$$\dot{\bar{x}} = A\bar{x} + B\bar{u}$$

$$\bar{x} = \int \dot{\bar{x}} dt$$

$$y = C\bar{x} + D\bar{u}$$

Algebraic Loops



every time you
arbitrarily pick
causality for $R = 1$
algebraic loop

$$\dot{P}_2 = e_2 = S_{e1} - e_3 = S_{e1} - e_4 = S_{e1} - R_4 f_4 = S_{e1} - R_4 (f_3 - f_5)$$

$$\ddot{P}_2 = S_{e1} - R_4 \left(\frac{P_2}{I_2} - f_6 \right) = S_{e1} - R_4 \left(\frac{P_2}{I_2} - \frac{e_6}{R_6} \right)$$

$$\dot{P}_2 = S_{e1} - R_4 \left(\frac{P_2}{I_2} - \frac{e_5 - e_7}{R_6} \right)$$

$$e_5 - e_7 = e_4 - \frac{q_8}{C_8} = R_4 f_4 - \frac{q_8}{C_8}$$

effort on the arbitrary causality R

$$e_4 = R_4 / \left(\frac{P_2}{I_2} - \frac{e_4 - q_8/C_8}{R_6} \right)$$

$$e_4 = R_4 \left(\frac{P_2}{I_2} - \frac{e_4 - q_8/c_8}{R_6} \right)$$

solve for e_4

two state variables

$$e_4 = \frac{R_4 P_2}{I_2} + \frac{R_4 q_8}{R_6 c_8}$$

$$\left(1 + \frac{R_4}{R_6} \right)$$

replace

$$\dot{P}_2 = S_{c_1} - e_4$$