Implement the slider-crank shown below in a 20sim bond graph. The slider moves along an inclined slot, and begins at the flattened configuration shown. Generate a motor model (with armature resistance and inductance, shaft inertia and bearing resistance) to drive the crank.

Part 1 - Open Loop

Using the parameters below, simulate the motion of the slider crank starting from rest, with zero crank angle. Pick a motor voltage that will give continuous rotation. Plot crank angle and angular velocity vs. time. What is the approximate steady state speed of the crank in rpm? It will be variable, so you can calculate RMS speed using a 20sim block in the Block Diagram library.

Part 2 - Closed Loop

Implement a controller to maintain a steady crank speed of 120 rpm. Plot the crank angular velocity and motor torque vs. time.

In addition to your plots, print out your bond graphs and include any workings.

Parameters

Slider-crank

\[ J_{G2} = 0.0417 \text{ kg-m}^2 \]
\[ J_{G3} = 2.667 \text{ kg-m}^2 \]
\[ m_2 = 2 \text{ kg} \]
\[ m_3 = 8 \text{ kg} \]
\[ m_4 = 20 \text{ kg} \text{ (slider)} \]
\[ a = 0.5 \text{ m (length of AB)} \]
\[ b = 2.5 \text{ m (length of BC)} \]
\[ K = 200 \text{ N/m (spring stiffness). Assume spring is undeflected when } \theta_2 = 0. \]
\[ R = 64 \text{ N-s/m (damping in parallel with spring)} \]

Motor

\[ L = 0.002 \text{ H (winding inductance)} \]
\[ K_m = 10 \text{ N-m/A (motor constant)} \]
\[ R_m = 10 \text{ ohms (winding resistance)} \]
\[ J_m = 0.02 \text{ kg-m}^2 \text{ (rotor inertia)} \]
\[ R_b = 0.0001 \text{ N-m-s/rad (bearing friction)} \]