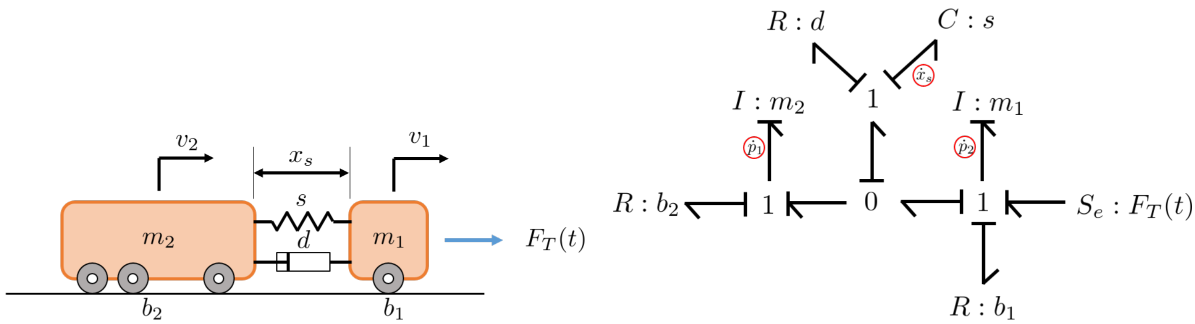
Lab 2: System modelling and simulation

MCHA3400

Semester 1 2024

Introduction

Modelling and simulation of physical systems are fundamental skills required for designing and analysing mechatronic systems. In this lab, we will practice these skills by constructing a simulation of an idealised truck model, shown in Figure 1a.



(a) A simple dynamic truck model.

(b) Bond graph of a simple truck system.

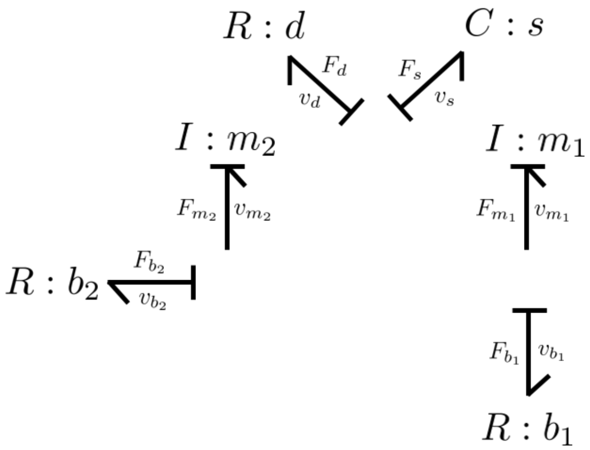
Figure 1: A simple truck system with corresponding bond graph.

To achieve this, you will first construct functions for each of the system CCRs and SSRs as indicated by the bond graph. Using the causal strokes of the graph, you will then substitute the functions into each other to obtain the system state equations for simulation.

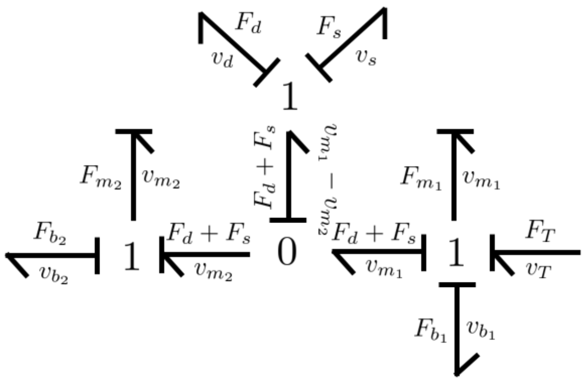
This lab is worth 1.5% of your overall grade. Show your results to your tutor by the end of your lab session to be awarded marks. Labs will also be accepted at the beginning of your lab 3 session. After this point in time, no marks will be awarded.

Lab task: Simulation of simplified truck system

In your tutorial session, you derived a set of ODEs that describe the dynamics behaviour of the truck system shown in Figure 1a. This was done by first constructing the bond graph shown in Figure 1b and then propagating the power variables to obtain a state-space model. You also de-constructed the graph into the CCRs and SSRs shown in Figure 2.



(a) Truck CCRs.



(b) Truck SSRs.

Figure 2: CCR and SSR de-constructions of the truck bond graph.

The CCRs of the spring and damper interconnecting the truck masses are non-linear, described by

$$\begin{aligned} F_s(x_s) &= \frac{1}{c}(x_s - l_0) + \frac{\beta}{x_s} + \frac{\beta}{2l_0 - x_s} \\ F_d(v_d) &= b_d v_d |v_d|. \end{aligned} \tag{1}$$

where F_s, F_d are the forces exerted by the spring and damper, respectively, x_s is the displacement state associated with the spring, v_d is the relative velocity between the two damper terminals, l_0 is the rest length of the spring and b_d, c are coefficients. As all other CCRs are assumed to be linear, the total system CCRs are described by

$$\begin{aligned} \dot{p}_1 &= F_{m_1} \\ v_{m_1} &= \frac{1}{m_1} p_1 \\ \dot{p}_2 &= F_{m_2} \\ v_{m_2} &= \frac{1}{m_2} p_2 \\ F_d &= F_d(v_d) \end{aligned} \qquad \begin{aligned} \dot{x}_s &= v_s \\ F_s &= F_s(x_s) \\ F_{b_1} &= b_1 v_{b_1} \\ F_{b_2} &= b_2 v_{b_2} \end{aligned} \tag{2}$$

The SSRs for the system can be read off the graph in Figure 2b to find

$$
\begin{aligned}
v_{b_2} &= v_{m_2} & & \\
F_{m_2} &= F_d + F_s - F_{b_2} & F_{m_1} &= -F_d - F_s - F_{b_1} + F_T \\
v_d &= v_{m_1} - v_{m_2} & v_T &= v_{m_1} \\
v_s &= v_{m_1} - v_{m_2} & v_{b_1} &= v_{m_1}
\end{aligned} \tag{3}
$$

Tasks:

a) Create a new file in Matlab and include the commands `clear` and `clc` at the top of your script. Create a parameters structure called `params` that will store all of the system parameters. Add the following parameters to the structure.

$$
\begin{aligned}
m_1 &= 600 & b_d &= 1400 \\
m_2 &= 1200 & c &= 9.8 \times 10^{-4} \\
b_1 &= 10 & l_0 &= 0.8 \\
b_2 &= 6 & \beta &= 5
\end{aligned} \tag{4}
$$

b) For each of the static CCRs in (2), create an anonymous function describing the component behaviour with the appropriate inputs and outputs.

c) For each of the SSRs in (3), create an anonymous function describing the power variable interconnections with the appropriate inputs and outputs.

d) For each of the dynamic CCRs in (2), create an anonymous function that describes the individual state equations of each state. Make use of the previously defined CCRs and SSRs to describe each state's behaviour as a function of states and inputs. Once completed, combine all states into a single state equation of the form

$$
\dot{x} = f(x, u), \tag{5}
$$

where $x = [p_1, p_2, x_s]$ is the state of the system and $u = F_T$ is the input.

e) Making use of the function defined in the previous steps, create a simulation of the truck system using an ODE solver in Matlab. Simulate the system over the time interval $t \in [0, 300]$ and plot the displacement $x_s(t)$ and momentum of the masses as a function of time. Use the ODE45 solver with a relative tolerance of 1×10^{-6}, initial conditions $p_1(0) = 0, p_2(0) = 0, x_s(0) = 0.8$ and input force

$$
F_T(v_{m_1}) = 300 - v_{m_1}\frac{28}{300}. \tag{6}
$$

Your solution should agree with Figure 3.

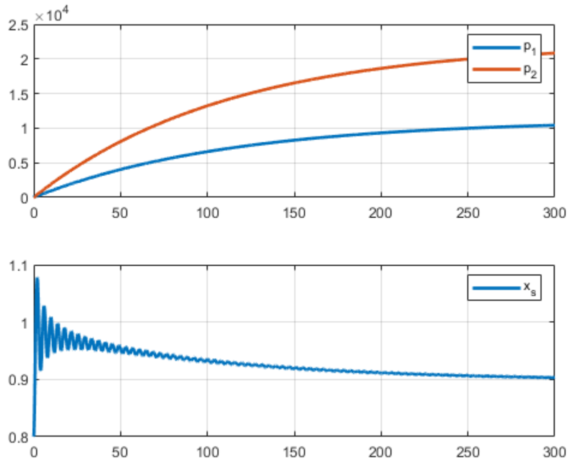


Figure 3: Simulation results from task c).

f) Modify your code to use the following input

$$F_T(v_{m_1}, t) = \begin{cases} 300 - v_{m_1}\frac{28}{300}, & t < 300 \\ 0, & t \geq 300. \end{cases} \tag{7}$$

Simulate the system for the time interval $t \in [0, 600]$ and plot the results. Your solution should agree with Figure 4.

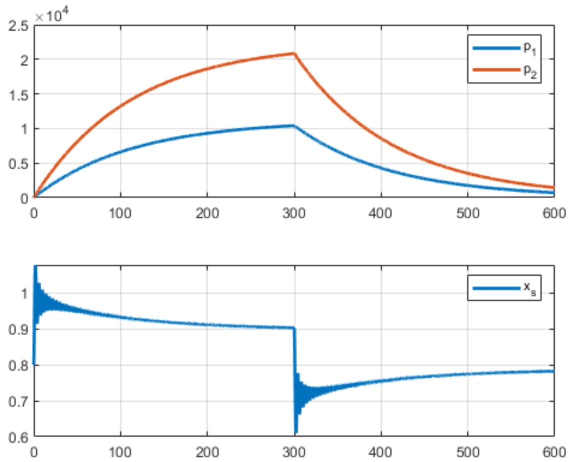


Figure 4: Simulation results from task d).

Tip

For complex inputs, you can declare a function at the bottom of your script that computes the appropriate logic. In this example, you may want to create a function at the bottom of your simulation file that resembles that shown in Figure 5.

```
%% Functions
% Define input force
function force = F_T(t,v_m1)
    % Add logic for input force here
end
```

Figure 5: You can create a function that describes the input.

g) Using your simulation output, determine the peak power supplied from the input force to the mass 1.

Recommendations

Here are some suggestions on what you should work on next:

- There are many ways in which the Matlab plots can be modified. Modify your output of task 3 so that the axis of your plots are labelled, a legend appears on the plot, the text has font size 11 and the lines have width of 2.
- Your plots currently show the momentum of the two masses and the spring displacement. Modify the momentum plots to show the velocity of the masses, rather than the momentum.