# ES 3011 C-2019

# Lab #4: Transfer Functions & Transient Response

## INTRODUCTION

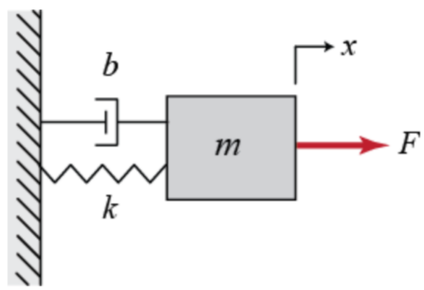
In this lab, you and a partner will create transfer functions and assess the transient response of applied system models representing a mass-spring-damper, a RLC circuit, a car in motion, and a DC motor and will use this to plot the open-loop step responses. In Simulink, you will begin modeling the cruise-control car.

Please have the following outline for your report:

1. A few sentences of introduction of the topic of the lab.
2. Answers to each problem with concise explanations on your process in solving and outcome.
3. A paragraph concluding the report explaining the goals, what you learned, and any other conclusions.

# MATLAB

### I) MASS-SPRING-DAMPER SYSTEM



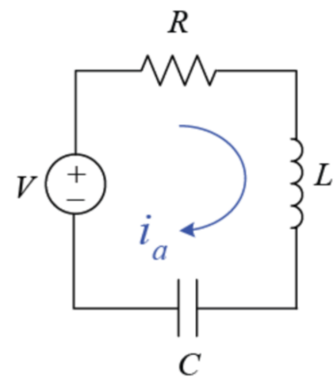

$$F(t) - b\dot{x} - kx = m\ddot{x}$$

This system has the following properties:

| | | |
|---|---|---|
| m | Mass | 5 kg |
| k | Spring Constant | 1.0 N/m |
| b | Damping constant | 0.5 N.s/m |
| F | Input Force | 2 N |

1. Write the transfer function of this system.
2. Plot the open-loop step, impulse, and ramp response.
3. Gather the following data in Matlab from the open-loop step response:
    a. Peak Response, settling time, rise time, and max overshoot.
4. Calculate the values from 3 analytically.

## II) RLC CIRCUIT




$$V(t) - Ri - L\frac{di}{dt} - \frac{1}{C}\int idt = 0$$

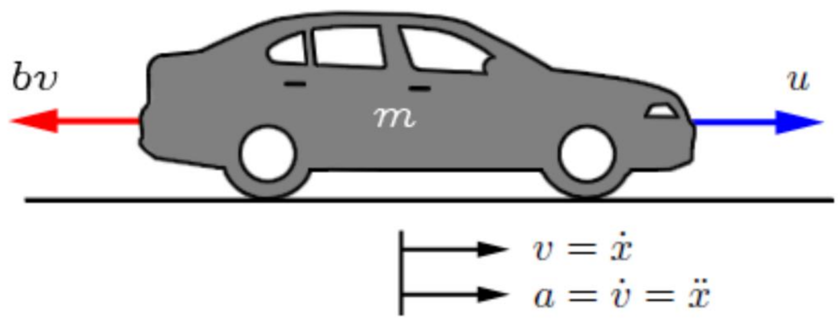
Reminder to put in terms of q. Also use the transfer function relating to q, not i.

This system has the following properties:

| | | |
|---|---|---|
| L | Inductance | 5 H |
| C | Capacitance | 300 uF |
| R | Resistance | 100 Ohm |

1. Write the transfer function of this system.
2. Plot the open-loop step, impulse, and ramp response.
3. Gather the following data from the open-loop step response:
    a. Peak Response, settling time, rise time, and max overshoot.
4. Find the values from 3 analytically.

## III) CRUISE-CONTROL CAR



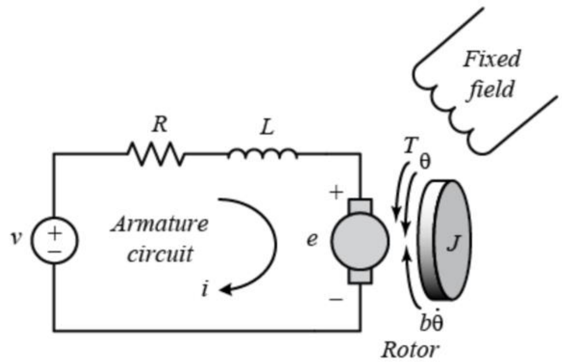

$$m\dot{v} + bv = u$$

This system has the following properties:

| | | |
|---|---|---|
| m | Vehicle mass | 1500 kg |
| b | Damping Coefficient | 50 N.s/m |
| u | Input Force | 500 N |

1. Write the transfer function of this system.
2. Plot the open-loop step, impulse, and ramp response.
3. Gather the following data from the open-loop step response:
   a. Peak Response, settling time, rise time, and max overshoot.
4. Find the values from 3 analytically.

## IV) MOTOR POSITION




Newton's 2nd Law and Kirchhoff's voltage law gives us these equations:

$$J\ddot{\theta} + b\dot{\theta} = Ki$$

$$L\frac{di}{dt} + Ri = V - K\dot{\theta}$$

This system has the following properties:

| | | |
|---|---|---|
| J | Moment of inertia of the Rotor | 3E-6 kg.m^2 |
| b | Motor friction constant | 3.5E-6 N.s/m |
| K | Electric Force and Motor Torque Constant | 0.025 V/rad/sec |
| R | Electric Resistance | 5 Ohm |
| L | Electric Inductance | 3E-6 H |

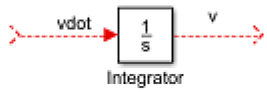
1. Write the transfer function of this system.
2. Plot the open-loop step, impulse, and ramp response.
3. Gather the following data from the open-loop step response:
    a. Peak Response, Settling time, rise time, and max overshoot.

# SIMULINK

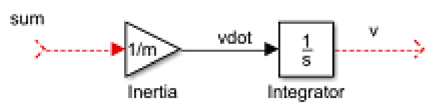
## CRUISE-CONTROL: MODELING

a) Insert an Integrator block (from the Continuous Library) and draw lines to and from its input and output terminals.

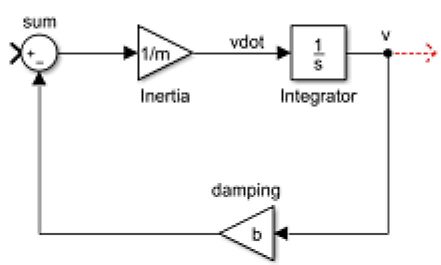
b) Label the input line "vdot" and the output line "v" as shown below. To add such a label, double click in the empty space just above the line.




c) Since the acceleration (dv/dt) is equal to the sum of the forces divided by mass, we will divide the incoming signal by the mass.
   i) Insert a Gain block (from the Math Operations library) connected to the Integrator block input line and draw a line leading to the input of the Gain block.
   ii) Edit the Gain block by double-clicking on it and change its value to "1/m".
   iii) Change the label of the Gain block to "inertia" by clicking on the word "Gain" underneath the block.



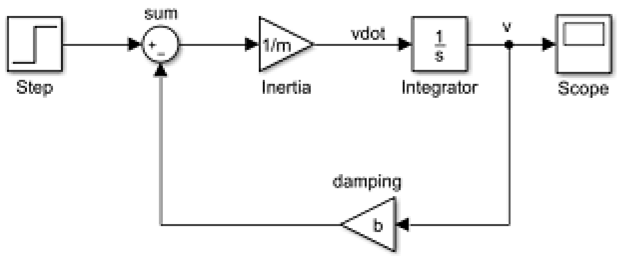

d) Now, we will add in the forces which are represented in Equation (1). First, we will add in the damping force.
   i) Attach a Sum block (from the Math Operations library) to the line leading to the inertia Gain block.
   ii) Change the signs of the Sum block to "+-".
   iii) Insert a Gain block below the Inertia block, select it by single-clicking on it, and select **Flip Block** from the **Rotate & Flip** menu (or type **Ctrl-I**) to flip it left-to-right.
   iv) Set the block's value to "b" and rename this block to "damping".
   v) Tap a line (hold **Ctrl** while drawing) off the Integrator block's output and connect it to the input of the damping Gain block.
   vi) Draw a line from the damping Gain block output to the negative input of the Sum Block.




e) The second force acting on the mass is the control input, u. We will apply a step input.

i) Insert a Step block (from the Sources library) and connect it with a line to the positive input of the Sum Block.

ii) To view the output velocity, insert a Scope block (from the Sinks library) connected to the output of the Integrator.




f) To provide an appropriate step input of 500 at time equals zero, double-click the Step block and set the Step Time to "0" and the Final Value to "u".

g) To simulate this system, first, an appropriate simulation time must be set.
   a. Select Parameters from the Simulation menu and enter "120" in the Stop Time field. 120 seconds is long enough to view the open-loop response.

h) Set the physical parameters to match the properties given for the cruise-control car.

i) Run the open-loop simulation and screenshot the resulting graph.

j) Take a screen shot of your final model.

k) Comment on how this result compares with that of the MATLAB plot.