Assignment 8: ODE and Simulink

Solution   Instructor: Trani

Problem 1

Consider the train equation of motion presented on page 41h of the course notes Matlab Advanced Functions (http://128.173.204.63/courses/cee3804/cee3804_pub/Notes13_Matlab_inter_cee3804.pdf). The acceleration equation for the high-speed train is of the form

$$\frac{dV}{dt} = A + BV + CV^2$$

$where:$

$V =$ is the train velocity (m/s)

$\frac{dV}{dt} =$ is the train acceleration (m/s-s)

A, B, C are model coefficients (see page 41h)

Task 1

Create a basic Simulink model to solve the differential equation of motion (shown above) and obtain a velocity profile for the train in the first 300 seconds after the train leaves the station. Export the values of velocity and time from your Simulink model and make the plot of velocity vs. time in Matlab.
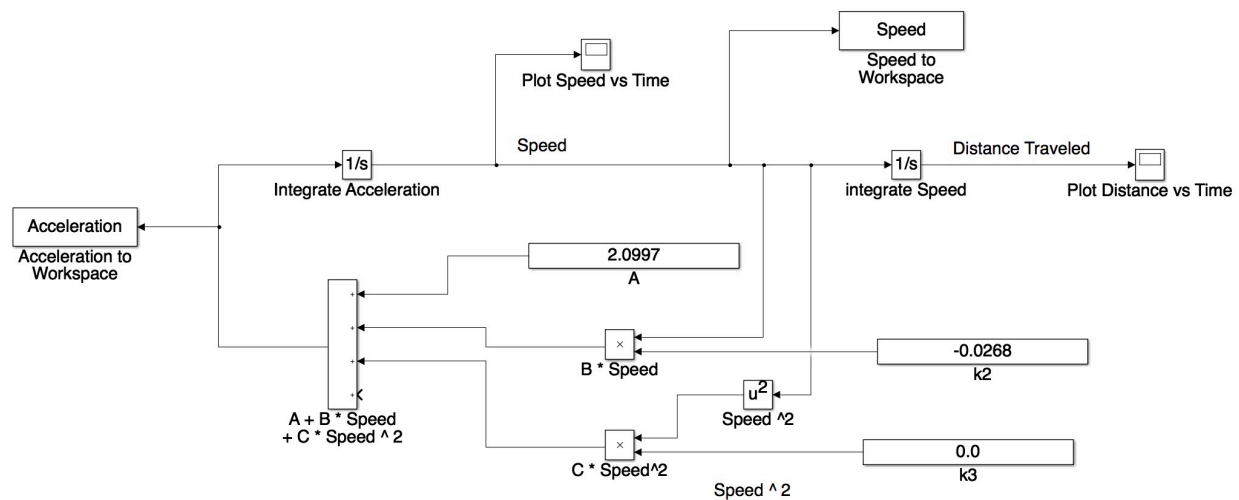

Figure 1. Basic Simulink Model.

Task 2

Improve the model created on Task 1 to estimate the distance traveled by the train after leaving the station. Export the values of velocity and time from your Simulink model and make the plot of velocity vs. time and distance vs time in Matlab.

Task 3

The equation shown above states that under maximum power (full throttle), the train will accelerate at a rate of 2.1 m/s-s as the train leaves the station. The application of full throttle consumes large amounts of electric power and hence the train operator would like to save in energy bills. Assume the train engineer applies 75% of maximum acceleration potential as the train starts at

the station. The engineer targets the use of 85% maximum acceleration potential when the train reaches 40 m/s and 95% acceleration potential at or above 65 m/s. Reprogram your Simulink model to solve the new equations of motion for speed and distance. Compare the profiles obtained in Task 2. Comment.

Define **TS** as the throttle setting parameter. **TS** is a non-dimensional parameter that indicates the fraction of acceleration to be used by the train engineer for a given train speed. For example, at 40 m/s the value of **TS** is 0.85 (85% of the maximum acceleration potential). The value of **TS** is a function of train speed (V) and is programmed in Simulink as a table lookup function (see Figures 2 and 3). The revised acceleration of the train is,

$$\frac{dV}{dt}_{revised} = (A + BV + CV^2) * TS$$

$where:$

$V =$ is the train velocity (m/s)

$\frac{dV}{dt}_{revised} =$ is the revised train acceleration (m/s-s)

A, B, C are model coefficients

TS = Throttle setting (dimensionless)

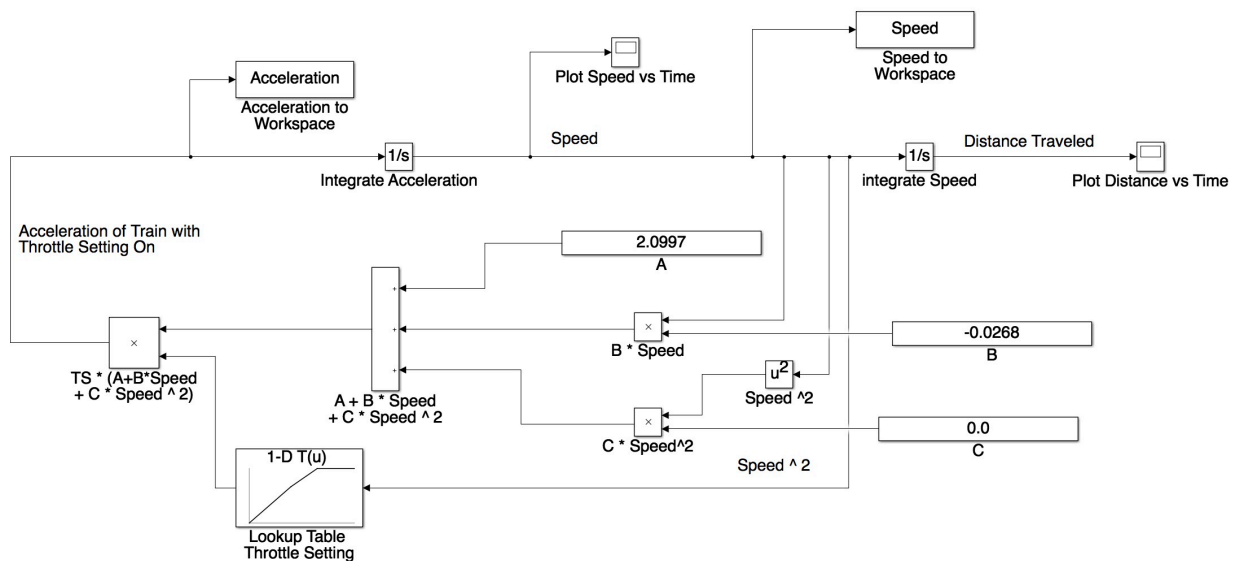TS is a function of V (train speed)

Figure 2. Revised Simulink Model with Variable Throttle Control. The Table Lookup Block Simulates the Throttle Control Described in the Problem Statement.

The solutions for train speed with and without throttle setting control are shown in Figure 4 and 5. It is clear that the throttle setting influences the train speed profile. With the throttle setting control on, the train reaches 73 m/s in 120 seconds. At maximum throttle, the train reaches 75 m/s in 120 seconds. Note that a time t=40 seconds, the train travels at 52 m/s if full throttle is used. When partial throttle is used, the train speed is 46 m/s instead.

Function Block Parameters: Lookup Table Throttle Setting

Lookup Table (n–D)

Perform n–dimensional interpolated table lookup including index searches. The table is a sampled representation N variables. Breakpoint sets relate the input values to positions in the table. The first dimension corresponds to t input port.

| Table and Breakpoints | Algorithm | Data Types |

Number of table dimensions: 1

Table data: [0.75 0.85 0.9 0.9]

Breakpoints specification: Explicit values

Breakpoints 1: [0 40 65 100]

Figure 3. Table Lookup Function Specification for Train Throttle Control. The Table Data Contains the Values of the Throttle Setting to be Used (i.e., independent variable). The Breakpoints Contain the Values of Speed Used to Define the Throttle Setting (i.e., Speed).
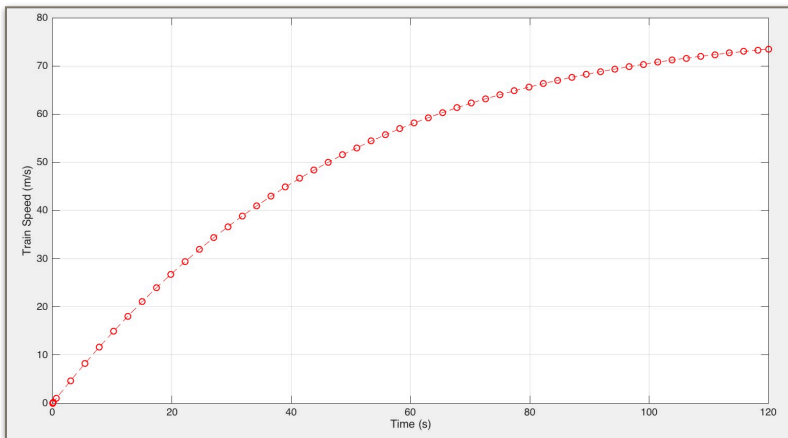

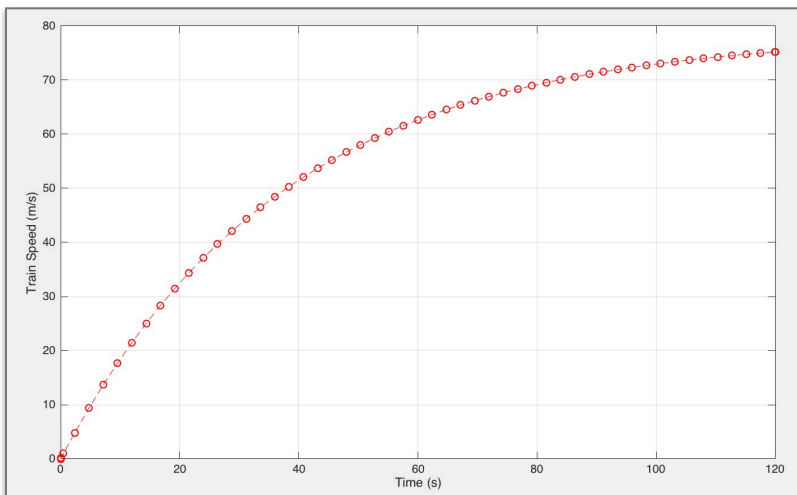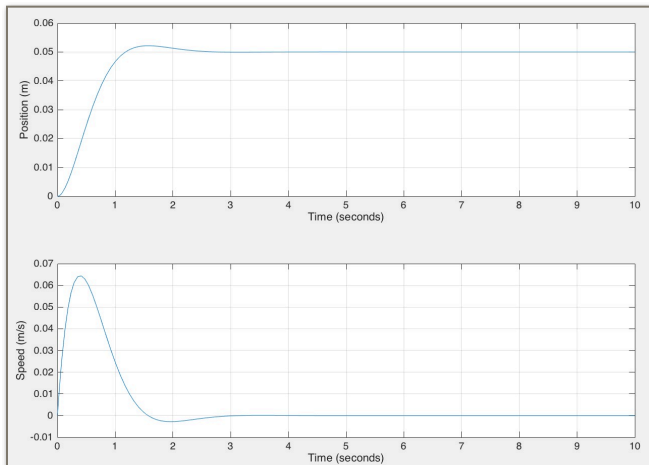Figure 4. Train Speed with Throttle Setting Control.

Figure 5. Train Speed without Throttle Setting Control.

Problem 2

Consider the mass-spring-damper (SMD) system described in class and shown in Figure 1. See equations at: http://128.173.204.63/courses/matlab/matlab_tutorial.html (under second order mechanical system). A 500 Newton object is attached to a 4000 N/m spring and a 500 N/m/s damper as shown in Figure 6.
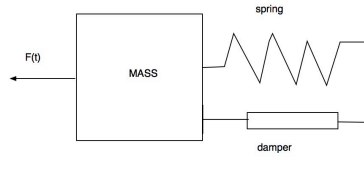

Figure 6. Mechanical System.

Task 1
Create a basic Simulink model to solve the differential equations of motion (for position and velocity of the SMD system). Solve the equations of motion if a 50 Newton constant force - f(t) is applied to the SMD system. Export the values of velocity, position and time from your Simulink model and make necessary plots to visualize the system. Explain how long will it take for the SMD system to reach 5% of its peak displacement.

Task 2
Solve the SMD using the Matlab Runge-Kutta (RK) 5th order method. Plot the position and velocity profiles of the SMD system as a function of time using two viewports in the same figure. Verify that the Simulink model created in Task 1 gives the same answers as the RK 5th order algorithm.

Task 3
Suppose that you are in charge of making design changes to the mechanical system. This type of system can be used in buildings to dampen oscillations due to earthquakes or wind (see article http://www.wind.arch.t-kougei.ac.jp/info_center/ITcontent/tamura/10.pdf).Your task is to specify the numerical value of a new damper so that the SMD reaches 5% of its pealk displacement in less than 3 seconds. Note that since dampers are expensive, your task is to make the damper light, yet powerful to restore the system quickly to a steady-state condition.

Solution:

Steady state position of the SMD system is 0.05 meters (after a long time). This is the position after a long period of time after the initial disturbance. Using a damper with 2000 N/m/s produces the following response. This response achieves the goal specification of 5% maximum displacement from the steady-state condition. The maximum displacement is 0.0522 m and the displacement at t=3 seconds is 1e-4 meters.

Problem 3

Read the article Tuned Mass Dampers (https://en.wikipedia.org/wiki/Tuned_mass_damper) and answer the following questions.

a) Explain the principle of operation of tuned mass dampers in civil engineering.

b) Are there any examples of tuned mass dampers in US structures? Name 3 examples.

c) Name the tallest structure in the World with a tuned mass damper.

d) Besides buildings, what other man-made structures employ tuned dampers? Provide some examples.

Read the article: http://www.wind.arch.t-kougei.ac.jp/info_center/ITcontent/tamura/10.pdf and explain in a couple of paragraphs the meaning of design damping ratio. You can always reference other articles on the subject.