**ES301 Nonlinear Simulation Lab**

**Introduction**

Suppose that we are interested in the design of the suspension of a Monster Truck with a hardening spring. (see Figure). The following is a simplified schematic of the truck and suspension for a single wheel.



z2

z1



Where m is the truck mass, k is the suspension spring constant, and b is the coefficient of viscous friction for the shock absorber. Z1 is the position of the axle, and Z2 is the position of the chassis. Because the force of gravity is counteracted by a steady-state compression of the spring, it can be disregarded in this scenario.

**Design**

As design engineers we need to select the shock absorber (the value of b) so that the truck does not “bottom out” when it drives over a passenger car.

1. Create two mathematical models of the system. In the first assume a linear spring and in the second assume a hardening spring. The position of the bottom of the wheel, Z1, is the input and the position of the chassis,Z2, is the output. Create a simulation diagram for both models. Carefully detail ALL of your assumptions, inputs and outputs.

2. Create a script file, called ‘truck\_response.m’, with all your parameter values as follows. When complete, run the file.

% Script to open figure and load variables

figure(1);clf; % Select figure 1 and clear it

hold on; % allow many plots on one page

Tmax = 5; % we want to simulate for 5 sec

Tmin = 0; % we start at t=0

k= 3500; % lb/ft spring constant

m = 150; % lb sec^2/ft pound mass

height = 3; % ft height of car

% to be rolled over

b = 50; % lb sec/ ft damping constant.

% Will be changed later!

3. MATLAB can be used to simulate the response of the truck it rolls onto a car. Assume that the input, the wheel position Z1, undergoes a step input from 0 to 3 feet. Note: While the step change in axle position is physically impossible, this is a simplifying assumption that allows a first look at the problem. Be careful how you set the parameters of the step input.

4. Run the script file. Plot Z1 (linear spring) vs time and Z1 (nonlinear spring) vs time on the same figure. Do they respond as expected? **Would changing the value of the step input affect the differences seen in the responses?**

5. System design frequently includes a trade-off between performance and safety. If the distance between the truck chassis and the axle gets too small, there is a danger of “bottoming out”. However, we would like to the chassis to move as much as possible to absorb more energy, making a more comfortable ride, and maintaining tire contact.

You need to determine the optimum value of b so that, after the peak response, Z2 comes as close as possible to the red line without dipping below it. You will write a script file to help in the design.

1. Modify truck\_response.m. Below the definition of the height, in place of the definition of b, read the minimum value of b, bmin=input(‘Enter minimum B ‘);. Do the same for the maximum value of b.
2. Create an interval in b so that there are five equally spaced values, db=(bmax-bmin)/4;.
3. Modify the script file as needed so that the simulation runs 5 times, once with each value of b and plots the responses on the same graph. (*Hint*: use b=bmin:db:bmax as the index of the for loop). Place your for loop in such a way as to minimize any unnecessary repeated computations.
4. Add a line that will automatically run your simulink file inside the loop, using the command sim(‘your\_simulink\_file\_name‘). Note that Simulink automatically know when the value of B has changed.
5. (still inside the loop) Add a line that prints Z2 as a function of time. Make sure to set “hold on”.
6. When the loop is done you should have a plot that looks like the one below. At the end of your script (not in the loop). Add labels for the axis using the xlabel and ylabel command. Play with the axis or grid commands to get a nice figure. Also, it is desirable to show the numerical values of the minimum and maximum value of damping in the title. For this to be possible the numerical values in the variable names must be converted to string values:

title(['Damping: b=',num2str(bmin),' to b=',num2str(bmax)]). Hint: to draw the red line use:

plot([0 5],[2 2],`r—`); Do you understand what this means?

6. Run your code and use 50 as bmin and 1000 as bmax. Your graph should resemble the one below. Print it out. Use your pen or the interactive buttons at the top of the figure window to mark which curve corresponds to each value of b.



7. Use your program to determine the optimum value of b so that, after the peak response, Z2 comes within 0.02 feet of the red line without dipping below it. You may need to use the axis command or the zoom button to zoom in on and evaluate your design, and may need to increase the refine factor (found in your SIIMULINK model window under Simulation>Configuration Parameters>Data Import/Export) to smooth your curves. Keep a log of the design cycle in the following table:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Iteration | Bmin | Bmax | Best B  (does not dip below Z2 =2 after peak) | Distance to Z2 = 2 |
| 1 |  |  |  |  |
| 2 |  |  |  |  |
| 3 |  |  |  |  |

Fill in additional rows as needed…

Be sure to print a copy of the best design and a close up plot which illustrates that you met the design criteria.

8. Repeat Steps 5-7 for the nonlinear model.

**Report**

Follow all the guidelines for memorandum format. Embed MATLAB plots in body, attach code as an enclosure. In addition to any expected items, be sure to include and discuss the items below.

Include:

* Your script file,
* Your plot of the response with b = 50 from step 5
* Your reproduction of the sample plot from step 7 with labeled curves
* Your design table indicating the successful design
* A plot showing the response over 5 seconds of the final design
* A plot of the final design which is zoomed in on the area of interest which will allow me to verify that you came within 0.02 feet of the red line without dipping below it

Discuss:

* Your design process, including how you decided what range of b you decided to simulate based on the previous iteration and any intuition you had about how the system would respond to changes in b.
* Did adding the nonlinearity change the number of iterations needed to find the optimal value of b?
* How would the response change if we assumed a softening spring?