Assignment: The Mass-spring-damper system

An introduction to Mathworks SimMechanics

1 Introduction

It is the aim of this exercise:

- To demonstrate the software Matlab+Simulink+SimMechanics and,
- To apply it to a basic system: The mass-spring-damper system. Determine compliance, transmissibility in the frequency domain, and the response to a specific displacement or force input.

It is assumed that the student has a good working knowledge of the Matlab+Simulink combination, and this course focuses on the use of SimMechanics.

This short description is not intended to be complete in its description. The help function of Matlab is always available, the teaching staff could also know (some of) the answers and the user forum on the Mathworks website contains discussions on a plethora of questions, problems and modeling challenges.

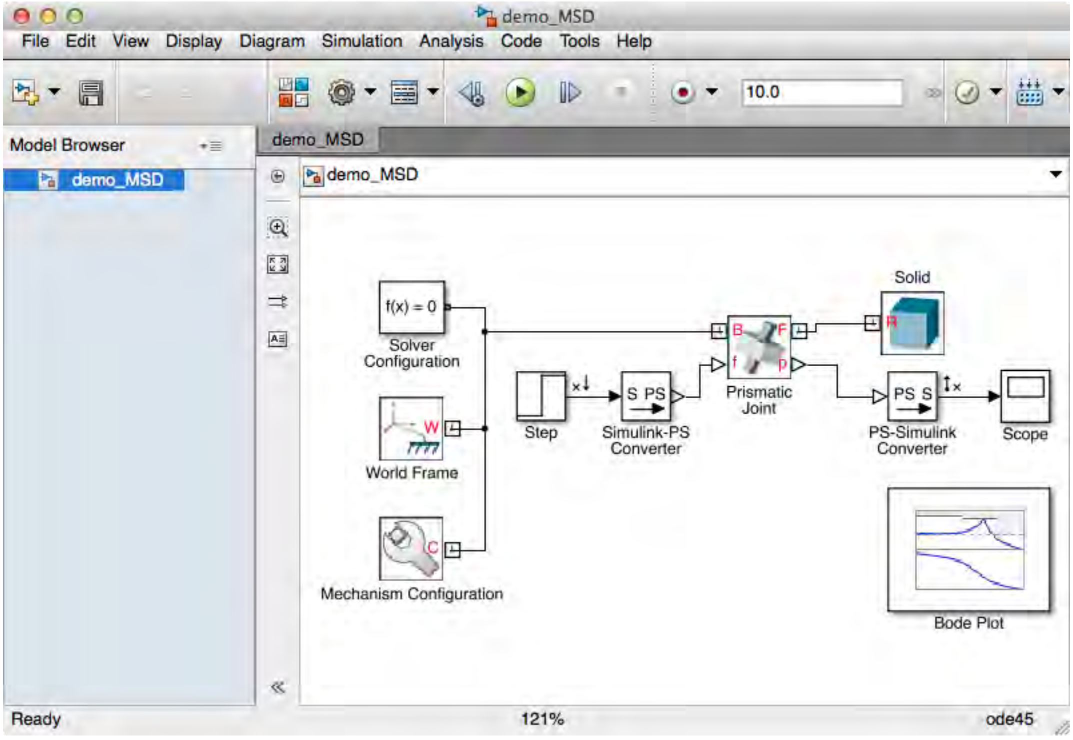
Write a short report on your progress, referring to the assignment description by noting the section and question number, and collect all your weekly reports in one master report.

2 Introduction to SimMechanics

Let's determine the dynamic behavior of the simplest of mechanical systems: The 1-mass-spring-damper system.

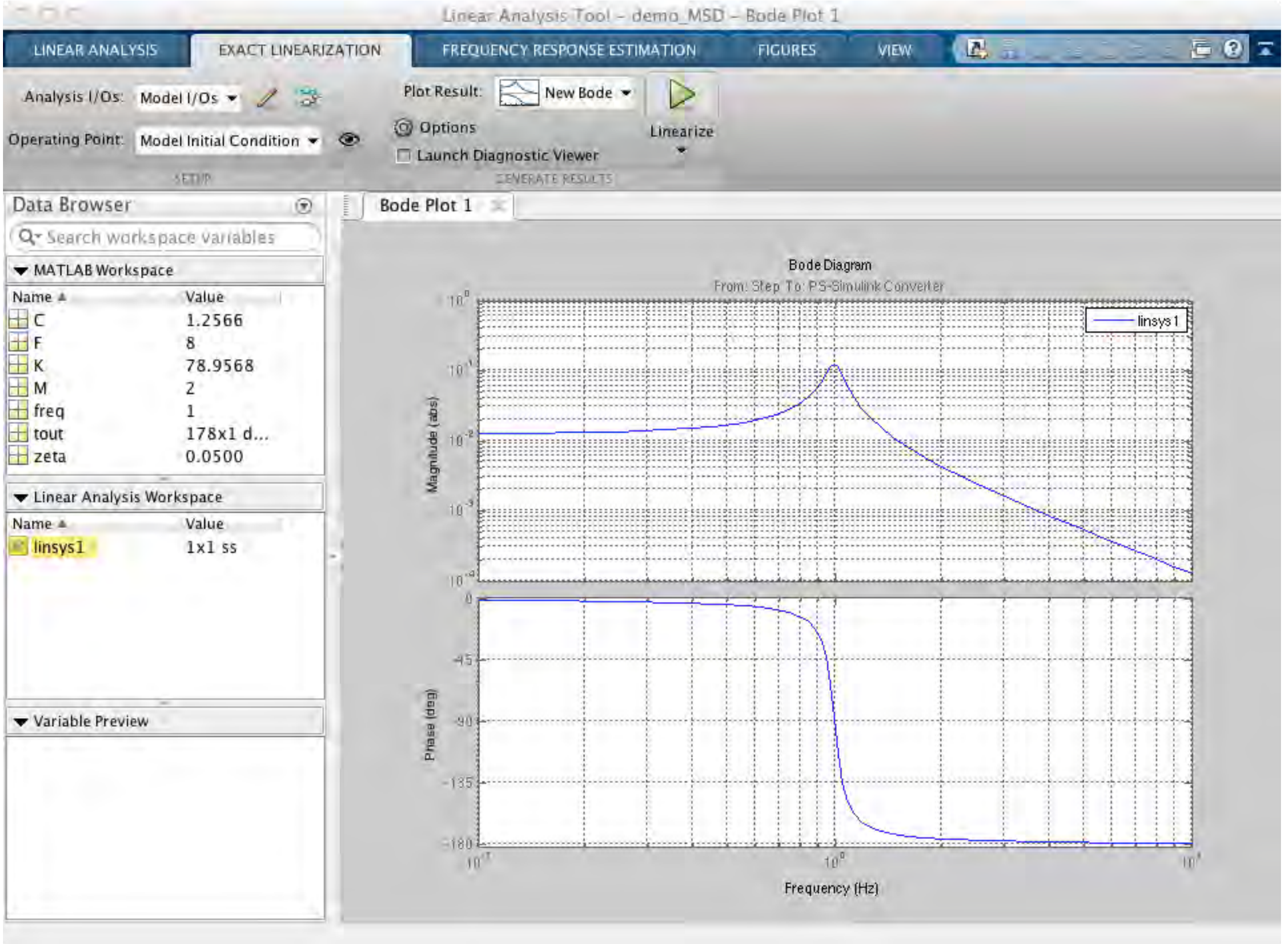
1. Start matlab
2. >> simulink
   This command initializes the simulink system, and opens the Simulink Library Browser.
   We could now start using the simulink blocks in Simscape – SimMechanics – Second generation, however there is a short-cut to start with a new system that already contains some of the required blocks:
3. >> smnew
   In SimMechanics rigid bodies are connected together using joints. The definition of the connection points inside the rigid bodies occurs thru the use of frames. Frames define coordinate systems relative to each other and are the connection points for joints and external forces and torques. Every simulation requires (at least) one world frame, which is a fixed frame against which all other frames are referenced. Furthermore some solver configuration settings, and a mechanism configuration (gravity direction!) are required. In order to connect the non-causal SimMechanics blocks to the causal simulink signal blocks an input and output block are required.
4. Find the prismatic joint in the library and drag that to the system.
5. The prismatic joint allows for translation along one axis (local z-axis) and in that direction a spring and damper and an actuation force operating between base frame and follower frame may be defined. Double click the block to get to the parameters window and set the spring and damper values (K N/m, C Ns/m) and make sure the actuation allows for an external force, and that the sensing output for the position is active. Set a point mass with value M kg.
6. Add the step signal source to the system. Set a step at 1s of F N.

7. Connect the blocks to obtain this system:

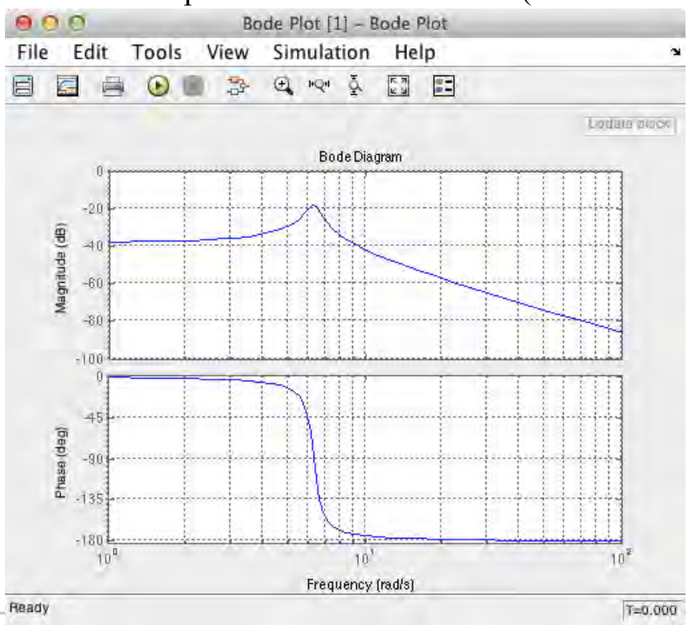


8. A powerful property of the Matlab – Simulink – SimMechanics combination is the fact that the Matlab workspace can be used to set and calculate parameters used in the simulation.
   Let's assume a value for the mass M equal to 0.025 kg. Type in the command window:
   >> M = 0.025;
   And a value of 0.1 N for the force:
   >> F = 0.1;
   But we can also calculate required properties. Let's assume that a natural frequency of 100 Hz is required, and a dimensionless damping constant of 5%. We need to calculate the values for the spring stiffness K and damping coefficient C:
   >> freq = 1;
   >> zeta = 0.05;
   >> K = (2*pi*freq)^2*M;
   >> C = 2*zeta*sqrt(K*M);
9. A very useful feature of the Matlab – Simulink combination is the fact that a Simulink worksheet can refer to Matlab workspace variables. However, Matlab variables are not automatically saved together with the Simulink model. A method to realize this is to define a Simulink callback function:
   File – Model Properties – Model Properties – Callbacks tab
   And then in the correct callback function add the commands that you would like to execute at the start or the end of a simulation.
10. The simulation can now be run and the displacement of the mass observed in the Scope. A typical response, however not corresponding to the parameter values listed before, is:

11. In order to determine the properties in the frequency domain, let's perform a system analysis. Add input and output points at the signal lines that we want to combine in the transfer function. Right click on the signal line from the step source to add a Linear Analysis Point input. Do the same for the signal line to the scope for the output.
12. There are 2 ways to start a linear system analysis:
    Analysis – Control design – Linear analysis,



or add a bode plot window to the model (from Simulink Control Design: Linear Analysis Plots).



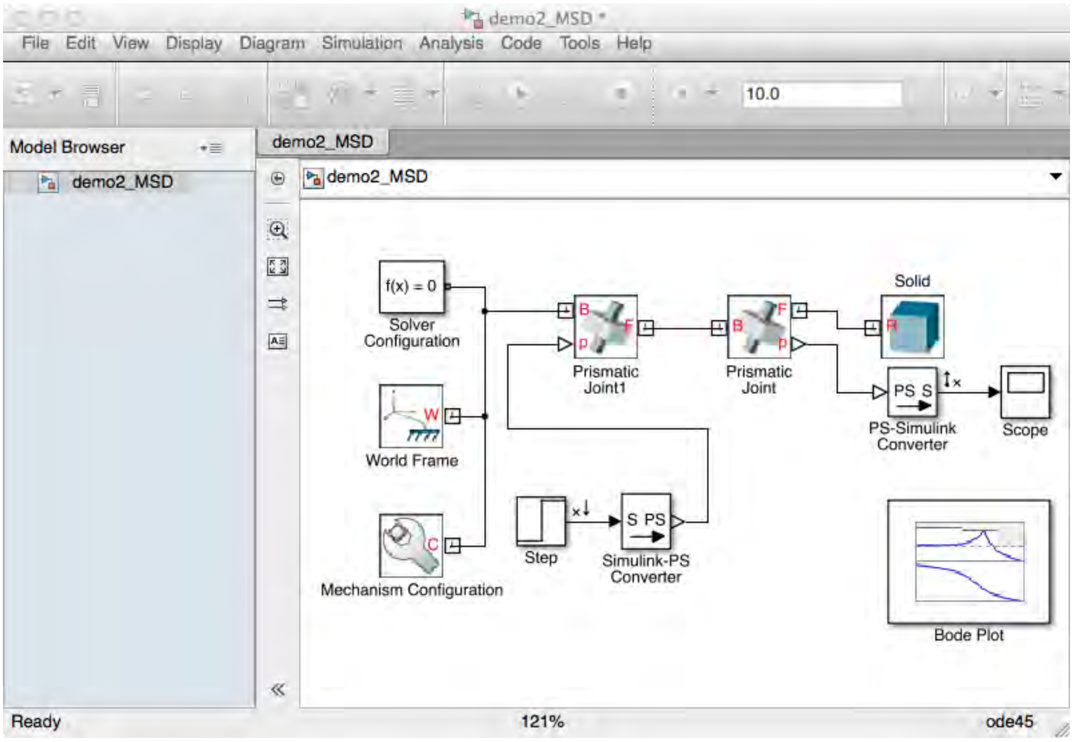
The latter method has the advantage of a nice quick result and a direct availability of the results with the simulation.

The first method generates a linsys1 variable that can be dragged in the Linear Analysis Tool from the Linear Analysis Workspace to the MATLAB Workspace to be further analyzed, for instance to generate the transfer function:

```
>> tf(linsys1)
ans =
From input "Step" to output "PS-Simulink Converter":
        0.5
  ----------------------
  s^2 + 0.6283 s + 39.48
```

Much more can be done with this type of linear systems variable. See the Mathworks documentation for an extensive explanation.

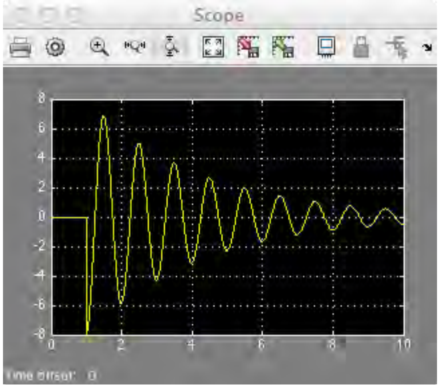
13. Calculating the transmissibility:
    In order to introduce external vibrations thru the floor a new Prismatic Joint is added that represents the movement of the floor relative to the world frame.



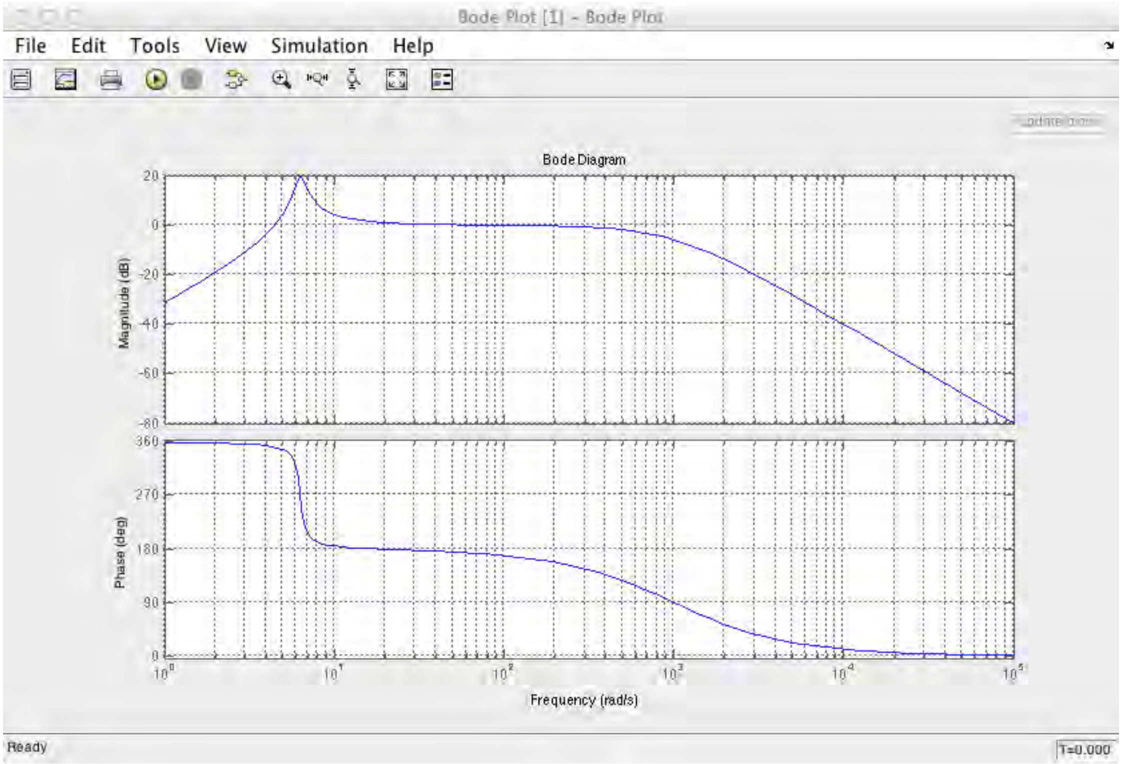
In order to prescribe a displacement SimMechanics also requires the velocity and acceleration to be defined. Displacement only is not sufficient!

The Simulink- PS Converter needs to be set to provide the input 1st and 2nd derivatives by using a 2nd order filtering of the input.

14. Calculate the step response:



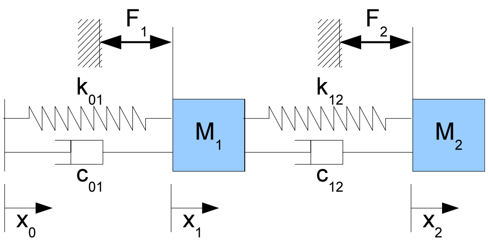
15. And the transmissibility:



16. HOLD ON – This curve does not correspond with the figure found in chapter 3 of R. Munnig Schmidt: "The Design of High Performance Mechatronics". WHY? Discuss. Modify the model to fix this issue.

3 The 2-Mass-Spring-Damper system

Expand the previous system to the 2-mass-spring-damper system, and plot the different transfer functions.



1. Add a 2nd mass and spring damper combination to the 1-mass-spring-damper system that we have developed. Parameters: $M_1 = 0.025$ kg, $M_2 = 0.0025$ kg, $k_{01} = k_{02} = 10^4$ N/m, $\xi_{01} = \xi_{12} = 0.05$.
2. Plot the following compliance functions: x_1/F_1, x_2/F_2, and the cross-terms: x_1/F_2, x_2/F_1, and check the results.
3. Plot the transmissibility functions: x_1/x_0, x_2/x_0 and check the results.