

Individual Assignment

Practice Modelling and Simulation

Module Systems Modelling



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Deadline: 5/11/2021

1. Introduction

Industrial carts often use polyurethane tyres due to their heavy duty application needs. In these use cases, the warehouse floor or any other working surfaces typically have standards which dictate the smoothness of the surface. However, in the real world there might be bumps such as expansion joints, fallen objects or lack of standard flooring. One way to study the effect of driving over bumps is to use a quarter car model (a quarter cart model in this case) as shown in Figure 1.

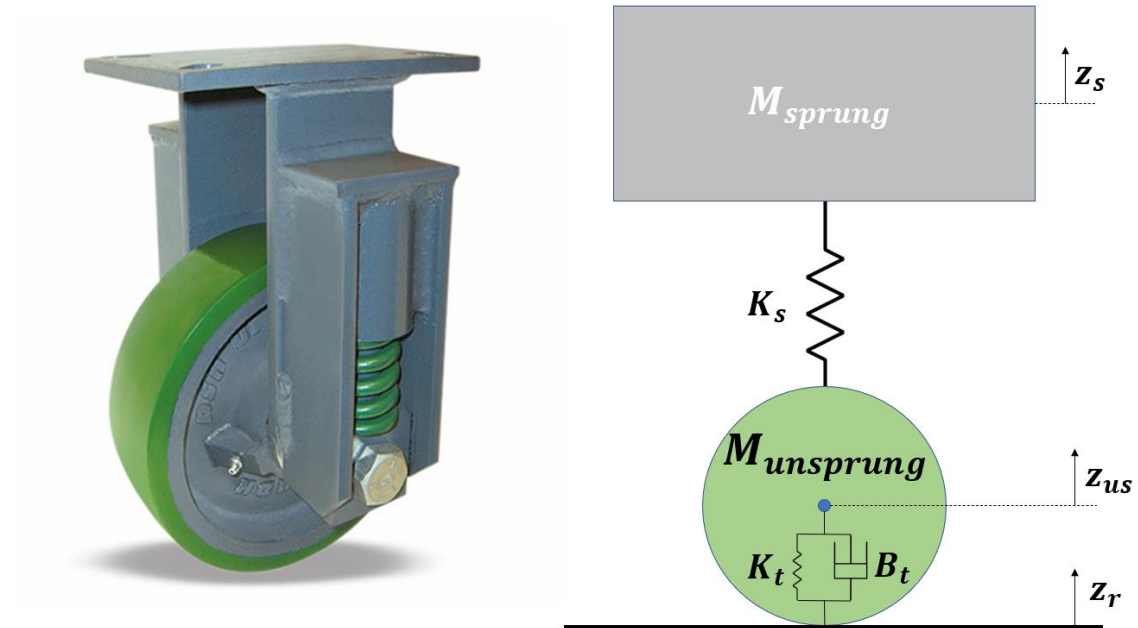


Figure 1: Schematic of a quarter cart model

The system consists of:

- The sprung mass of the cart (quarter of the vehicle mass and payload) ' M_{sprung} '
- The unsprung mass of the cart (the mass of the wheel) ' $M_{unsprung}$ '
- The spring with a stiffness ' K_s '
- The spring with a stiffness ' K_t '
- The damper with a damping coefficient ' B_t '
- The displacements of the masses from their static equilibrium positions are ' z_{us} ' and ' z_s '
- The displacement of the road surface is ' z_r '

Assumptions:

- The dynamics of the tyre are modelled as a parallel spring and damper combination
- The damping due to friction in the wheel bearing and between the spring and its vertical slot are neglected
- The effect of acceleration due to gravity is not modelled, since the masses being at their equilibrium positions already accounts for that effect

2. Problem Definition

An industrial cart is to be used in an indoor environment where a payload needs to be handled carefully (in a brewery, hospital, small factory, etc). For our particular application, the payload cannot handle a vertical acceleration of more than $\pm 1.4 \text{ [m/s}^2\text{]}$. A spring loaded caster (as shown in Figure 1) is available in the market but its suspension behaviour with a desired payload of 750 [Kg] has to be checked to verify if it is fit for indoor use. The indoor floor surface has bumps 5 [mm] in height.

Hence, this assignment should answer the following questions:

- Is the spring and tyre combination of the caster suitable for limiting the vertical acceleration of the payload to a maximum of $\pm 1.4 \text{ [m/s}^2\text{]}$ during a maximum road displacement of 5 [mm]?
- If not, what parameter of the caster has to be changed to suit the application?

3. Simulink Modelling

The spring loaded caster has a spring with a stiffness of 140 [KN] and a polyurethane tyre with a spring and damping constant of 300 [KN] and 5000 [Ns/m] respectively. The bumps are modelled as road/floor vertical displacement. The industrial cart has a vehicle mass of 350 [Kg].

Using a free body diagram for the quarter cart model, the vertical behaviour of the caster and quarter vehicle can be modelled with the following equations:

$$M_{sprung} \ddot{z}_s = -K_s(z_s - z_{us})$$

and

$$M_{unsprung} \ddot{z}_{us} = K_s(z_s - z_{us}) - K_t(z_{us} - z_r) - B_t(\dot{z}_{us} - \dot{z}_r)$$

Model these differential equations in Simulink, where your work will be graded on the following aspects:

- Correct and clearly commented and sectioned Matlab script.
- Correctly modelled equations in Simulink.
- Clean and optimized modelling in Simulink.
- Development of a one click run system. One click in the Matlab editor should generate every scenario of the system. (Note: The assessor will not make any changes in the files to run a different scenario; the model will be considered incomplete without this)

4. Model Verification

Model verification is a step in which you run your system for different scenarios and observe whether the results you are getting are consistent with your knowledge of the system. Verification ensures that the model has been translated from differential equation into a Simulink diagram correctly. The following model parameters should be chosen to verify your model:

$$M_{sprung} = \frac{350 + 750}{4} = 275 \text{ [Kg]}$$

$$M_{unsprung} = 15 \text{ [Kg]}$$

$$K_s = 140 \text{ [KN]}$$

$$K_t = 300 \text{ [kN]}$$

$$B_t = 5000 \text{ [Ns/m]}$$

Run the following scenarios with a fixed time step of 0.001 [s], show the simulation results and comment briefly on the results.

- Give a step input for a road displacement of 2 [mm] (flat bump). Run the simulation for 10 seconds and analyse the displacement, velocity and acceleration of both the masses.
- Make an input for simulating a transition from a flat-to-incline-to-flat surface. Choose the dimensions of the input wisely and motivate it in your report. Run the simulation for 25 seconds and comment on the response of the system.

Your explanation (comments) should include answers to the following questions:

- Why did you choose the specific outputs?
- Why did you model this specific input? (Keep in mind that the input should make sense and should be related to what would exist in practice; do not choose it randomly)
- Does the output make sense? What makes you think it is correct or wrong. Is it something you expected? If yes, why did you expect it and if no, why did you not?

The following outputs plots should be generated from the simulation:

- A figure displaying the excitation as input.
- Figures displaying the chosen outputs.

Your work will be graded on the following aspects:

- Correct and clear plots (with a proper title, axes, legends, units and meaningfulness of the values) of the outputs and inputs.
- Correct and critical comments on the behaviour of the system.
- Correct and reasonable choice of input and outputs.
- Critical and clear conclusion of the results.

5. Model Validation

Validation of the model is an important step within a project. How well does our model replicate test results? Does our modelled system behave like the actual physical system within a certain framework? These questions can only be answered through validation. We can validate our model using comparison to the test data but in many cases, the test data is not available to us. In that case, changing the parameters (i.e. sensitivity analysis) can be used to validate our model. Use the following approaches to validate your model:

- Import the data file "InputOutputData.xlsx" of the test results and match them with the obtained model results, choose the vehicle parameters given above. In case you find deviations (which is the most obvious case), comment on why could these deviations be present and because of what reasons. Use the input data from the imported file to run the simulation and compare the model results with the actual results.

- Make a sensitivity analysis of 10% increase and decrease of the parameters (one parameter at a time) M_{sprung} , $M_{unsprung}$, K_t , K_s , and B_t , on the outputs of the system. Comment on the change in system behaviour.

Your work will be graded on the following aspects:

- Correctly importing the data into Matlab & Simulink.
- Correctly choosing (with proper explanation) and implementing a filter on the imported data.
- Correctly analysing the imported data.
- Correct validation of the model data with the test data (within the same figure and plot).
- Correctly performing the sensitivity analysis using loops (*for* loops or any other form)
- Correct choice of outputs with proper reasoning.
- Correct conclusion on the change in behaviour with changing parameters (with correct reasoning).

6. State Space

Create the state space for the system. Find the A, B,C and D matrices for this system and model it in Simulink to match the results with the differential equation model. What do you observe?

Your work will be graded on the following aspects:

- Correct formation and modelling of state space.
- Correct and neat representation of state space in the report.
- Correct validation of the state space.

7. Transfer Function

After you have achieved the state space, use MATLAB to convert the state space into the transfer function (or you can create a transfer function of the entire system from scratch as well). Match the results of the transfer function with the state space and the differential equation model and comment what you observe. Is it possible to obtain a single equivalent transfer function of the system?

Your work will be graded on the following aspects:

- Correct formation and modelling of transfer function.
- Correct and neat representation of transfer function in the report.
- Correct validation of the transfer function.

8. Bonus Question

To add more complexity to the model, you have been asked to take into account the damping due to friction due to the vertical motion of the spring.

- Show how can friction due to damping be taken into account in the Simulink differential equation model. Explain the process.

9. Deliverables

- The modelling should be done in version 2018a or above.

- Single m-file containing all pre-processing commands, simulation commands and post-processing commands with proper comments and structure.
- All the necessary files required to run the model.
- A PDF-file (report) discussing all the necessary steps. This is done with respect to:
 - Verification and validation of the model
 - Necessary and readable figures generated by the m-file
 - The state space, and
 - The transfer function for the system
 - Conclusion
 - Analysis on the bonus part (if attempted)

10. Assessment

Your individual assignment will be assessed only if it meets the following conditions:

- The deliverables are handed in through soft-copy before or on the day of the deadline (November 5th, 2021) to the responsible lecturer in the HANDIN app.
Lecturers:
 - Aishwarya Aswal
 - Mitul Saini
 - Sanket Dutta
 - Nikhil Muthakana
- All files are delivered in one zip file. The page limit for the report is 8 pages including the cover page which must include your student details. The bonus question will not be a part of this limit.
- The report is properly structured and professionally formatted.
- Copying other student's Simulink model, Matlab-code, figures or conclusions is considered fraud and will be reported to the exam committee.
- No screenshots are used to visualize simulations results.

11. Marking Scheme

Deliverables are assessed according to the following criteria:

- Correct and organized model in Simulink (15p)
- Correct and logical coding in MATLAB (15p)
- Correct and complete visualisation (10p)
- Correct verification (20p)
- Correct validation (20p)
- Correct State Space (10p)
- Correct Transfer function (10p)
- Correct Bonus question (max 10p)