Practice Modelling and Simulation

Home Taken Exam

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Deadline: **26 January 2024**

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. This will of course result in (vertical) movement of the carts, which might be unwanted. One way to study the effect of driving over these "bumps" is to use a quarter car model (a quarter cart model in this case) as shown in Figure 1.

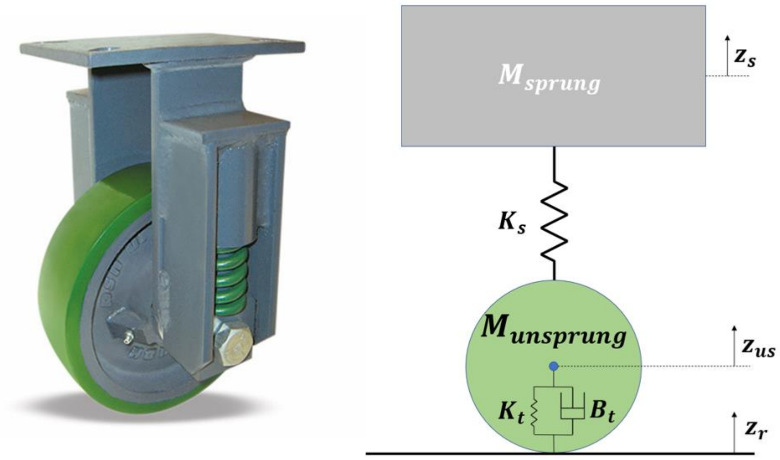

Figure 1: Schematic of a quarter cart model.

The system consists of:

- The sprung mass of the cart (quarter of the vehicle mass and its load) M_{sprung}
- The unsprung mass of the cart (the mass of the wheel) $M_{unsprung}$
- The spring (of the suspension) with a stiffness K_s
- The "spring" of the tyre with a stiffness K_t
- The "damping" of the tyre B_t

The road surface can have some vertical displacement, z_r which is the input to the system. Due to this vertical road displacement also the unsprung and sprung mass will have some vertical displacement (from their static equilibrium), z_{us} and z_s respectively.

For the given system we assume that:

- The dynamics of the tyre are modelled as a parallel spring and damper
- The damping due to friction in the wheel bearing and in the spring 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

The research:

In a hospital they use industrial carts with spring loaded casters as shown in Figure 1. The payload transported with those carts needs to be handled with care(!) and therefore it may not exceed a vertical acceleration of more than ±1.4 [m/s^2]. The question arises whether these spring loaded casters are suitable for the hospital usage, which has an indoor floor surface with bumps of 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 ±1.4 [m/s2] during a maximum road displacement of 5 [mm]?
- If not, what parameter of the caster has to be changed to suit the application?

2. Simulink Modelling

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

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

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

- Correctly modelled equation in Simulink.
- Clean and optimized model, including signal naming, subsystems & comments
- Correct, clearly commented and sectioned MATLAB script which runs the Simulink model.
- 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)

3. Model Verification

Model verification is a step in which you run your system for different scenarios and observe whether the results 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 <u>(pay attention to the units!)</u>:

$$M_{sprung} = \frac{cart\ mass + payload}{4} = \frac{350 + 750}{4}\ [kg]$$
$$M_{unsprung} = 15\ [kg]$$
$$K_s = 140\ [kN/m]$$
$$K_t = 300\ [kN/m]$$
$$B_t = 5000\ [Ns/m]$$

In the Simulink model's solver settings, use a Fixed-step solver type with a Fixed-step size of 0.001 [s]

<u>**Run the following scenarios, show the simulation results and comment on the results.**</u>

1. Give a step input for a vertical road displacement, $\boldsymbol{z_r}$, of 5 [mm] (flat bump). Run the simulation for 10 seconds and analyse the displacement and acceleration of both the masses.

2. Make an input for a scenario where the cart will drive over a bump with some inclination, e.g. the surface goes from flat-to-incline-to-flat. You can create the input yourself but it should make sense. Explain in the report how the input is created. Run the simulation for your desired input with an appropriate duration and comment on the response of the system.

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

- Why did you choose your specific method to model the input (in case of scenario 2)?
- 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? What can you conclude?

Your work will be graded on the following aspects:

- Correct, clear and visible plots (with a proper title, axes, legends, grid lines, units and meaningfulness of the values) of both the outputs and the inputs. (so generate the plots!)
- Correct and critical comments on the behaviour of the system.
- Critical and clear conclusion of the results.

4. Model Validation

Validation of the model is a crucial step within a project. How well does our model replicate test results? Does our modelled system behave like the actual physical system?

These questions can only be answered through validation. We can validate our model by comparing test data of a real physical system with the modelled data, but in many cases, the test data is not available. In that case, changing parameters (i.e. sensitivity analysis) can be used to validate our model.

Validate the model using the following approaches:

1. Import the data file **"PMS Exam - Quarter Car"** containing the test results and compare them with the obtained model results, choose the system parameters given above. In case you find deviations (which is the most obvious case), comment on why these deviations could 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.

2. Make a sensitivity analysis of 10% increase and decrease of at least three parameters (one parameter at a time). Comment / explain on the change in system behaviour.

Your work will be graded on the following aspects:

- Correctly importing the data into MATLAB & Simulink.
- Correctly analysing the imported data and commenting on its quality.
- Correctly choosing (with explanation) and implementing a filter on the imported data.
- Correct validation of the model data with the test data (within the same figure and plot).
- Correctly performing the sensitivity analysis by using "loops" (*for* loops or any other form).
- Correct outputs & conclusions on the change in system behaviour
- Overall conclusions of the model validation.

5. 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 (plots with state space outputs compared to differential equation outputs, make sure the plots make sense!).

6. Transfer Function

After you have achieved the state space, derive the transfer function of the system. Match the results of the transfer function with the state space and the differential equation model and comment what you observe.

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 (plots with transfer function outputs compared to differential equation and state space model outputs, make sure the plots make sense!).

7. Bonus Question

To improve the reality of the model, you have been asked to take into account the damping of the spring due to friction. Show how this can be implemented in your model. And next to this choose an appropriate value of this damping factor, taking into account the research mentioned in chapter 1. Introduction. Briefly explain your process in your report.

8. Deliverables

- All the necessary files required to run the model.
- The modelling should be done in MATLAB version **2018a** or above.
- **A one click run** system, including a single m-file (containing all pre-processing commands, simulation commands and post- processing commands with proper comments and structure) and a single Simulink model. **(Note: The assessor will not make any changes in the files to run a different scenario; the model will be considered incomplete without this)**
- A PDF-file (report) discussing all the necessary steps. This is done with respect to:
  - Necessary and readable figures (make sure the figures in the report are clear to see)
  - Verification and validation of the model
  - The state space of the system
  - The transfer function of the system
  - Conclusion
  - Analysis on the bonus part (if attempted)

9. 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 (**January 26th, 2024**) to the responsible lecturer in the HANDIN app:
  - Bas Hetjes
  - Karl Wallkum
  - Siddharth Ajaykumar
- 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 is not 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.

10. Marking Scheme

Deliverables are assessed according to the assessment form (which is uploaded on OnderwijsOnline), and consists of 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)