Course 4L150 "Vehicle Dynamics"

Third exercise (23/09/2008)

Part 1. Single track vehicle model - linear analysis

A different vehicle has undergone a similar test programme as shown in lecture 4, for both an unloaded condition (driver only) and a fully loaded condition (driver + passengers and cargo). The data is stored in a number of *.mat files and graphs are available when running the MATLAB-file *plot_measurements_unloaded.m* and *plot_measurements_loaded.m* respectively. In the *.mat files SI units are used: N, kg, m, rad, s. So angles are in radians and the velocity is expressed in m/s! When creating the plots the conversion to km/h and degrees is made. Note that the steering wheel angle δ_s and not the steer angle δ of the front wheel is measured, these angles are related by the steering ratio, $\delta_s = i_s \cdot \delta$ and $i_s = 17$. The wheel base of the vehicle equals $l = 2.51$ m.

When the handling tests were executed the vehicle was put on scales, with the following results:

unloaded vehicle	front axle: 784.0 kg	rear axle: 522.5 kg
loaded vehicle	front axle: 809.5 kg	rear axle: 840.0 kg

a) Based on loads on the axles determine the location of the centre of gravity. Calculate the distances a and b for both the unloaded and loaded condition.

Steady state cornering

b) Provided with this exercise are two measurement files *steady_state_circular_unloaded.mat* and *steady_state_circular_loaded.mat.* Make a plot of the corner radius for the different tests and determine an average corner radius R (various possibilities exist to check this, see VD sheets page 112).

c) For the steady state circular test we have information on the steering angle δ_s and vehicle side slip angle β as a function of the lateral acceleration a_y. Determine the cornering stiffnesses C_1 and C_2 so that the single track vehicle model agrees with the measurement results in the linear range (0 to 4 m/s^2). Create plots in which the model is compared with the measurements. Hint: modify both *plot_measurements* files and add the results of the linear bicycle model to the existing graphs. Do this for both the loaded and unloaded vehicle, the cornering stiffnesses may vary between the unloaded and loaded situation.

d) Calculate the understeer gradient. Is the vehicle understeered, oversteered or neutral steer? What about the differences between the unloaded and loaded vehicle?

e) Make a plot of the yaw velocity gain for the velocity range 0 to 100 km/h, both experiment and model in one plot. An example is shown on the VD sheets page 114. Again do this for the unloaded and loaded vehicle and add the graphs to both *plot_measurements* files (in the section dealing with steady-state cornering).

Random steering

f) The file *plot_measurements* also displays the transfer functions of the vehicle. The numerical data can be found in the files *pseudo_random_unloaded.mat* and *pseudo_random_loaded.mat.* The transfer functions of the vehicle were measured at an average forward velocity of 100 km/h. Create a state-space model of the linear bicycle model (see also VD sheets page 99). Calculate the transfer functions between the steering angle δ_s and lateral acceleration a_y and yaw velocity *r*. Use the values of the cornering stiffnesses C_1 and C_2 obtained under c) and estimate the yaw moment of inertia I_{zz} using the rules of thumb given on VD sheets page 70. Again plot both the measured transfer function and calculated transfer function in a single plot (magnitude and phase). You may tune the value of yaw moment of inertia I_{zz} to get the best match. Hint: again the easiest way to create this plot is to modify both *plot_measurements* files and add the transfer function of the model. Create the plots for both the unloaded and loaded case.

g) As was shown in lecture 4 adding the relaxation length of the tyre improves the accuracy of the model, see VD sheets page 120-123. Extend the state space description as given on page 99 so that it includes the tyre relaxation behaviour. Give the A, B, C and D matrix.

h) Similar to f) compare the measured transfer functions with the model results, now including the tyre relaxation length σ_1, σ_2. The relaxation length is dependent on the vertical load on the tyres, but the lateral stiffness of the tyres is (almost) constant (stiffness *k* in VD sheets page 120). Calculate the relaxation for the front and rear tyre by dividing the cornering stiffness through the tyre lateral stiffness, so:

$$\sigma_1 = \frac{C_1}{k} \quad \text{and} \quad \sigma_2 = \frac{C_2}{k}$$

Tune the magnitude of the tyre lateral stiffness k (and possibly the vehicle yaw moment of inertia I_{zz}) to get the best match with the measurements for both the loaded and unloaded case. Provide the plots of the transfer functions, has the model become more accurate?

Eigenfrequency analysis

i) By analysing the eigenvalues of the matrix A, we can determine the frequency and damping ratio of the system (see VD sheets page 101). Since the system dynamics of the vehicle are velocity dependent, this analysis has to be performed at different forward velocities. Using the results from f) and h) calculate the frequencies and damping ratios at 50, 100 and 150 km/h for the following four conditions:

- unloaded, no relaxation length
- loaded, no relaxation length
- unloaded, including relaxation length
- loaded, including relaxation length

Discuss the results.

J-turn

j) With the same vehicle a J-turn manoeuvre has been performed, both for the loaded and unloaded condition, the measurement data is given in the files Jturn_unloaded and Jturn_loaded respectively. Use the measured steering input as input for the simulation model and calculate the lateral acceleration and yaw velocity. The forward velocity may assumed to be constant and equals 100 km/h. Plot the simulation model results on top of the measurement results (see also VD sheets page 133). Compare the model with and without relaxation length, do you see an improvement? Make separate plots for the unloaded and loaded case.

Double lane change

k) Do the same as j) but now for the double lane change manoeuvre (files lane_change_unloaded.mat and lane_change_loaded.mat). Note that during the experiment the forward velocity is not constant and does not equal 100 km/h, calculate the average value. Compare the accuracy of the simulation model for part j) and k). What is the reason for the difference in accuracy?

Part 2. To be defined…

Part 3. To be defined…