Hand-in assignment: Module dynamics in Vehicle Dynamics Advanced, TME102 7.5 ETCS Study period 4, 2022

Fredrik Bruzelius,
email:fredrik.bruzelius@chalmers.se

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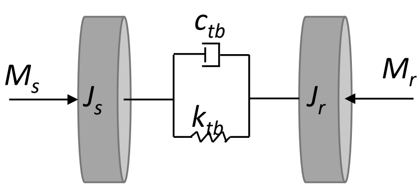
Abstract

This hand-in assignment is the examination of the first module on dynamics. Please hand in your solutions **before the 9th of April**. Please provide your solutions in CANVAS in pairs (two students). Remember that short and concise is beautiful, short answers will be favored. Simple calculation mistakes will be forgiven to a certain extent. The total sum of points on the assignment is 6, out of more than 2 is needed to pass (grade 3).

In this hand-in, we will focus on the dynamics of a steering system of a car. To simplify we only consider the mechanical parts and ignore the assistance system. We also assume that we only have one flexibility in the system, i.e. the torsion bar between the steering wheel and the steering rack. We assume that we can lump the pinion and rack into one inertia. We end up in a two-mass interconnected system according to the figure below with an input torque M_r originating from the road and an input torque from the driver on the steering wheel M_s.



- The inertia of the steering wheel is $J_s = 0.005 Nms^2/rad$.
- The sping and damping parts of the torsion bar are assumed linear with $k_{tb} = 100 Nm/rad$ and $c_{tb} = 0.1 Nms/rad$
- The lumped inertia of the steering rack (including gear ratios at pinion etc.) is $J_r = 10 Nms^2/rad$.

Linear systems

Assignment 1 (2p)
Formulate a state-space model of the system above. Show your chooice of state variables and how you end up with the matrices. Use the road feedback (through the steering rack M_r) as your input. Let us assume that the driver has taken the hands of the steering wheel ($M_s = 0$) and we want to study resulting steering wheel torque as our output ($J_s\ddot{\theta}_s$ where θ_s is the steering wheel angle)

Assignment 2 (1p)
Convert the system to transfer function form. Can you describe the steady-state (equilibrium) point in words? Is your model stable w.r.t. to this point? Is your system stable w.r.t to the input (torque from the road environment), i.e bounded input gets bounded output?

Assignment 3 (1p)
Plot the bode diagram of the model. Describe what you get, e.g. are there some extra interesting frequencies, what do they mean? What happens at low and high frequencies?

Nonlinear systems

Assignment 4 (2p)
Now we want to study the case when the driver is steering and applying a torque on the steering wheel, i.e. ($M_s \neq 0$). We can then assume that the reaction torque from the road is acting like a nonlinear spring relative to the angle of the rack. Furthermore, we assume that the main aligning torque from the road is given by the mechanical trail. For a constant speed, we can then model the aligning torque of the rack as,

$$M_r = \frac{2\mu F_z t_m}{\pi} \arctan(\frac{C_i \pi \theta_r}{2\mu F_z})$$

where t_m is the mechanical trail, F_z is the load on the front axle, μ is the coefficient of friction, C_i is the cornering stiffness, and θ_r is the rack angle. Derive the new nonlinear state-space system with M_s as an input. Let us say that we are interested in studying the road wheel angle, so we make θ_r the output. What is/are the stationary points of this system (i.e. when $M_s = 0$)? Can you make any conclusions on the stability of these/this stationary point(s) without the numerical values?

Useful Matlab commands

If you use Matlab (or Octave), there are some useful commands that might support you in this handin:

- tf() Create a transfer function object
- ss() Create a state space object
- bode() Plot a bode plot of a state space or transfer function
- pole() return the poles
- zero() return the zeros