TSFS09 3A

December 4, 2025

1 Introduction

The purpose of the project is to study the resonances in a drive line, and to study how potential oscillations can be damped. One important case where drive line oscillations typically occur is during tip-in and tip-out maneuver, i.e., when the drive line torque goes from negative to positive and vice versa. The task in this project is to design and implement a controller that damps oscillations during a tip-in/tip-out maneuver.

The controller will then be tested on a realistic drive line model, which is provided for you. The model is of a typical passenger car. To resemble a real case, only the engine speed sensor will be available for measurements in the simulation model. This sensor is chosen because it is typically the only one in the drive line with sufficient resolution for the given task. Data for the studied car is listed in a table below.

The Model with drive shaft flexibility (See model 14.2 in the course literature.) should be used to describe the vehicle driveline. The drive shaft flexibility model is used to include the effects of having inertia's in the final drive, transmission and the engine. These inertias are lumped together and connected to the wheel inertia by a damped torsional flexibility shaft (see figure 14.3 in the course literature.). To damp the oscillations in the driveline, a state feedback controller will be implemented. For a state feedback controller, all state variables of the driveline must be available. However, to decrease the costs and reduce the number of required sensors, an observer will be used to estimate necessary variables.

2 Drive-line Modelling

- Write down equations for a driveline including the four states drive shaft torsion, engine speed, wheel speed, and engine torque.
  - Consequently, you have to extend the driveline models in the chapter ”Driveline Modeling” in the course compendium with a state for the engine torque. This state can be modeled as a first order system with a time constant.
  - The input signal to the complete model describing the four states should be demanded engine torque and the output signal should be engine speed.
  - All the parameters (shown in Table 1) must be considered in the model except for the parameter “Engine maximum torque” that you will consider in the implementation of the controller.
  - Assume rolling condition for the wheels.
  - The friction torques in the system are assumed to be proportional to the rotational speeds.
  - The wheel assembly is assumed to me friction free ($b_w = 0$).
  - The rolling resistance can be assumed to be constant, the air drag can be neglected, and the vehicle can be assumed to drive at a horizontal road.
- Put the equations in standard linear statespace form and let constant terms be represented by a known constant input signal l according to:

  $$\begin{aligned} \dot{x} &= A\,x + B\,u + H\,l \\ y &= C\,x \end{aligned}$$

  The order of the states should be:

  x_1: drive shaft torsion,

  x_2: engine speed,

  x_3: wheel speed.

  x_4: engine torque.

3 Observers and Controllers

An observer can be used to reconstruct the states inside the system, using input control signals and measured output signals of the system and a system model. Observers are frequently used in vehicle industry to develop cost efficient diagnostics and controller systems, instead of using extra sensors. A system given by

$$\begin{aligned}\dot{x} &= A\,x + B\,u\\ y &= C\,x\end{aligned}$$

has the observer equation

$$\begin{aligned}\dot{\hat{x}} &= A\,\hat{x} + B\,u + K(y - C\,\hat{x})\\ y_{observed} &= C\,\hat{x}\end{aligned}$$

where the observer gain K has to be chosen. $y_{observed}$ is the output signal from the observer, containing the estimated states $\hat{x}$. In the project, reference signals for the states will be given. Note that the reference states are time varying and not constant.

- Draw a block scheme for a control system of the driveline consisting of an observer and a state feedback controller using the observed states. As mentioned above only engine speed is available for measurements. In the project reference signals for the states will be given. Note that the reference states are time varying and not constant. Since we have several states entering the controller, the residual $\bar{r} = x - \hat{x}$ has to be created.
- Write down the equations for an observer of the drive line model.
- Write the observer on the form

  $$\begin{aligned}\dot{\hat{x}} &= A_{obs}\hat{x} + B_{obs}u_{obs}\\ y_{obs} &= C_{obs}\hat{x}\end{aligned}$$

  where u_{obs} are all inputs to the observer and y_{obs} are all outputs from the observer. What is A_{obs}, B_{obs}, C_{obs}, u_{obs}, and y_{obs} expressed in A, B, H, C, u, l, y, $\hat{x}$, and observer gain?
- How can the observer gain be chosen?
- Write down the equations for a state feedback controller that uses the observed states. Remember that you will be given reference values for the states drive shaft torsion, engine speed, wheel speed, and engine torque.
- How can the feedback gain be chosen?

4 Vehicle Data

Parameter	Description	Value	Unit
m	Vehicle mass	1500	[kg]
r_w	Wheel radius	0.3	[m]
J_w	Wheel inertia	0.6	$[kgm^2]$
c_{r1}	Rolling resistance coefficient	0.147	$[m/s^2]$
J_m	Engine inertia	0.2	$[kgm^2]$
τ_e	Engine step response time constant	0.1	[s]
M_{max}	Engine maximum torque	400	[Nm]
i_t	Transmission ratio 1:st gear	3.4	[-]
J_t	Transmission inertia 1:st gear	0.13	$[kgm^2]$
b_t	Transmission friction (viscous damping coefficient)	0.1	[Nms/rad]
i_f	Final drive gear ratio	3.4	[-]
J_f	Final drive inertia	0.1	$[kgm^2]$
b_f	Final drive friction (viscous damping coefficient)	0.1	[Nms/rad]
k	Drive shaft stiffness	1000	[Nm/rad]
c	Drive shaft damping	1	[Nms/rad]

Table 1: Data for the passenger car studied in the project.