Short term storage systems Vehicle Propulsion Systems

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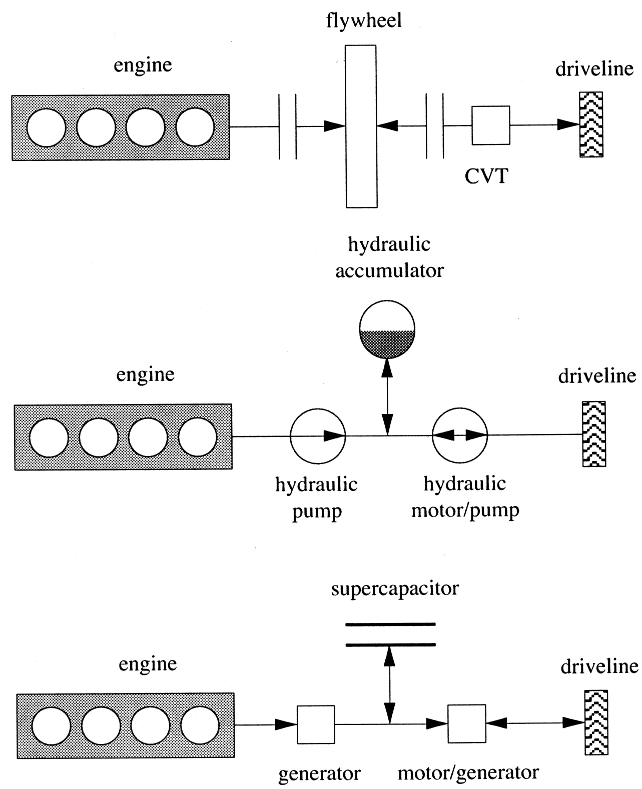

Contents

1 Purpose

This assignment deals with short term storage systems. The task is to apply everything you have learned during the course to modify an existing vehicle by adding one or more short term storage systems. The goal is to minimize the fuel consumption for the new vehicle using a smart control strategy and by choosing gear ratios and sizes of the add-ons in an optimal way.

Chapter 5 in the course book by Guzella and Sciaretta covers short term storage systems, while Chapter 4 covers Hybrid-Electric propulsion systems.

2 Assignment

The assignment is to be solved by using the QSS program package that can be downloaded as shown in the course book. A basic vehicle model is provided on the course-page as well as some vehicle/engine data. You should download this material before continuing with the assignment. Remember that you always can study the already implemented QSS examples and the QSS library.

The assignments below should be seen as guiding assignments during the vehicle design. The final report should at least contain the following

- Description and discussion of the final design and the design choices as well as parameters to the models and the model equations.
- Description and discussion of the QSS implementation. You are free to use other available QSS model blocks than the ones used in the basic vehicle model as long as the models conforms to he specifications in Section 3.
- Description and discussion of the control strategy.
- Efficiency plots showing in what operating points your components are operating. This is only necessary for components with a non constant efficiency and/or with torque/speed limits.

The report should be self explanatory and should not assume prior knowledge to any of the used short term storage systems or components. All assumptions should be discussed and the control strategy should be well described, discussed and motivated.

You should also make believable that your fuel consumption is accurate. That is, you should explain where your design saves the most fuel and how this affects the total fuel consumption.

Available model components and assumptions are listed in Section 3 below.

2.1 Evaluation of vehicle demands

The first assignment is to evaluate the provided vehicles performance and the drive cycles energy demand for the specific vehicle.

Therefore answer the following questions:

- What is the maximum acceleration of the vehicle?
- What is the maximum speed of the vehicle?
- In what operating points does the engine operate?

As a help to get you started there is a plot command, *mkPlots.m* that generates an efficiency map for the combustion engine as well as plots the used operating points. Remember that the Matlab/Simulink blocks *Scope* and *To Workspace* are your friends.

2.2 Design of new vehicle

Choose a short term storage concept. You may for example choose one of the concepts from the figure in Chapter 5 in the book by Guzella Sciaretta. However, you are free to connect any components you wish as long as it's physically feasible and provided that you add the components masses to the vehicle mass.

Write down the equations for all the components of the modeled vehicle. Then chose component sizes, gear ratios and other quantities. Plot finally the efficiency maps as well as limiting factors where applicable and ensure that

1. All operating points will be within the limits for the used components.
2. The components will be operating close to the maximum efficiency when working together.
3. The short term storage system[s] are large enough.

If you are uncertain of how to implement your concept in QSS you may look at the QSS built-in examples, especially *qss_example_shv*.

2.3 Design of control strategy

A control strategy is an algorithm that decides where to take the energy that is needed by the vehicle-drivecycle pair and how to utilize the short term storage. The control strategy should be designed so that the vehicle can perform the whole drive cycle without running into torque/speed limits and so that the Combustion engine as well as the other components are operated in an efficient way.

2.4 Evaluation of new Vehicle and control strategy

Show how your vehicle/control-strategy works together. Use efficiency plots that shows what operating points your components are operating in. Have you chosen the right gear ratios and sizes for your vehicle? Make a parameter study to see how sensitive your fuel consumption is to the model parameters for your short term storage components as well as your control strategy. Here it is important to not favor parameter choices that drains the short term storage system.

Also make believable that your fuel consumption is accurate. That is, explain where your design saves the most fuel and how this affects the total fuel consumption.

3 Available models and assumptions

First is a list of the available components you are allowed to add as well as common model assumptions and then a detailed walk through of some of the components.

- Flywheels
- Hydraulic Accumulators
- Supercapacitors

as well as the following *glue* components

- Gearboxes
- Electric motors
- Electric generators
- Continously variable transmissions
- Hydraulic pumps/motors
- Torque couplers and planetary gear sets
- Power electronics

Assume that all gearboxes has an efficiency of 0.98 and 100W of friction losses. All short term storage devices should have the same, or higher, *charge status* after the engine cycle as before, otherwise this has to be accounted for in a realistic way.

3.1 Short term storage systems

The equations for the short term storage systems are specified in the course literature unless available here as a reference. Parameters are to be chosen within reasonable limitations.

3.1.1 Flywheel

Assume that your are able to make flywheels using a material with $\rho = 8000$ [kg/m^3] and are able to choose b, d and q freely within reasonable limits. Also assume that manufacturing limitations gives you the flywheel parameters in Table 1. Assume that the total weight of the flywheel and bearings is 5% more than the flywheel mass.

Parameter	Description	Value
ρ	Flywheel density	8000 [kg/m^3]
ρ_a	Ambient air density	1.3 [kg/m^3]
η_a	Dynamic air viscosity	1.72 $\cdot 10^{-5}$ [Pa s]
b	Width	By choice
d	Diameter	By choice
q	Inner/Outer diameter ratio	$q \in [0, 1]$
d_w/d	Shaft/Wheel ratio	0.08 [-]
μ	Friction coefficient	$1.5 \cdot 10^{-3}$ [-]
k	Unbalance factor	4 [-]
ω_{max}	Maximum speed	6 3000 [rps]
m_{tot}	Total mass	$1.05 \cdot m_f$

Table 1: Flywheel parameters from the flywheel manufacturer.

3.1.2 Hydraulic accumulator

Assume that the Hydraulic Accumulator may be described by thermodynamic model together with the parameters in Table 2. Also assume that the total weight of the accumulator and it's components is described by the equations for a spheric accumulator. The weight of the oil should be at maximum charge. Note the importance of choosing the capacities so that the maximum pressure is never exceeded. It is advantageous to look at the implementation details for

Parameter	Description	Value
$V_{g,max}$	Maximum gas capacity	By choice
$V_{g,min}$	Minimum gas capacity	By choice
fc	Fluid capacity	By choice
ρ_{oil}	Hydraulic oil density	900 [kg/m^3]
T_w	Wall temperature	320 [K]
R_g	Gas constant	520 [J/kgK]
p_{max}	Maximum pressure	[400-800] [bar]
p_{init}	Pre charge pressure	125 [bar]
T_{init}	Pre charge temperature	320 [K]
h	Heat transfer coefficient	100 [W/Km^2]

Table 2: Hydraulic accumulator parameters from the manufacturer.

the Supercapacitor from the QSS library during the implementation. Use the volume fraction as state of charge.

3.1.3 Supercapacitor

Use the equations from the equivalent circuit paragraph in the literature and the parameters in Table 3 below. You are free to use as many as necessary.

Parameter	Description	Value
C_{SC}	Capacity per supercap	8 [F]
R_{SC}	Internal resistance	0.72 [Ohm]
$V_{max,SC}$	Maximum voltage of supercap	225 [V]
$P_{max,SC}$	Maximum power drain of supercap	175 [kW]
E_{SC}	Specific energy of supercap	2 [Wh/kg]

Table 3: Model parameters and assumptions supercapacitor

3.2 Glue components

The equations for the *glue components* are specified in the course literature unless available here as a reference. Parameters are to be chosen within reasonable limitations unless specified.

3.2.1 Gearbox

The gearbox equations are

$$P_{out} = \eta_{GB} \cdot P_{in} - P_0$$
$$\omega_{out} = \omega_{out} \cdot i_x$$

where P_0 is the friction losses and is direction dependent. (See for example the gearbox implementation in the QSS library.) The model parameters are listed in Table 4.

Parameter	Description	Value
η_{GB}	Gearbox efficiency	0.98 [-]
P_0	Idling losses	50 [W]
m	Gearbox mass	10 [kg/gear]

Table 4: Model parameters and assumptions for gearbox

3.2.2 Continously variable transmission

Alternative 1 Use the CVT efficiency approach and assume that the efficiency has the form

$$\eta_{CVT}(\omega_2, T_2, \nu) = \frac{\omega_{2,max} + \omega_2}{2\,\omega_{2,max}} \cdot \frac{9\,\nu_{max} + \nu - 10\,\nu_{min}}{10\,(\nu_{max} - \nu_{min})} \cdot \frac{T_2 \cdots}{\cdots} \tag{1}$$

Also assume that you are able to scale the CVT freely in the speed and torque domain and that the CVT works in both directions, i.e. you have to implement a direction detection if applicable.

Alternative 2 Assume that the CVT can be described as a normal gearbox but with a lower efficiency and higher idling losses. Parameters are listen in Table 5.

Parameter	**Description**	**Value**
η_{GB}	Gearbox efficiency	0.97 [-]
P_0	Idling losses	400 [W]
m	Gearbox mass	10 [kg]

Table 5: Model parameters and assumptions for gearbox

3.2.3 Hydraulic pump/motor

Use the Willians approach with the parameters in Table 6 below.

Parameter	**Description**	**Value**
P_0	Idling losses	300 [W]
e	Efficiency	0.8 [-]
m	Hydraulic pump mass	10 [kg]

Table 6: Model parameters and assumptions for hydraulic pump/motor

3.2.4 Torque coupler and planetary gear set

Assume that your torque couplers and or planetary gear sets are ideal without losses.

3.2.5 Power electronics

Neglect any power losses.

3.3 Energy converters

3.3.1 Electric motor

Assume that the electric motor is of the type from the QSS library. To help get you started the command *mkPlots.m* is available for download. The code shows how to plot engine performance maps and gives you an idea of how the efficiency of the electric motor in the QSS library is modeled . In Figure 1 the efficiency map for the electric motor has been plotted together with the torque limit. Assume that your engine is scalable using the scale parameter.

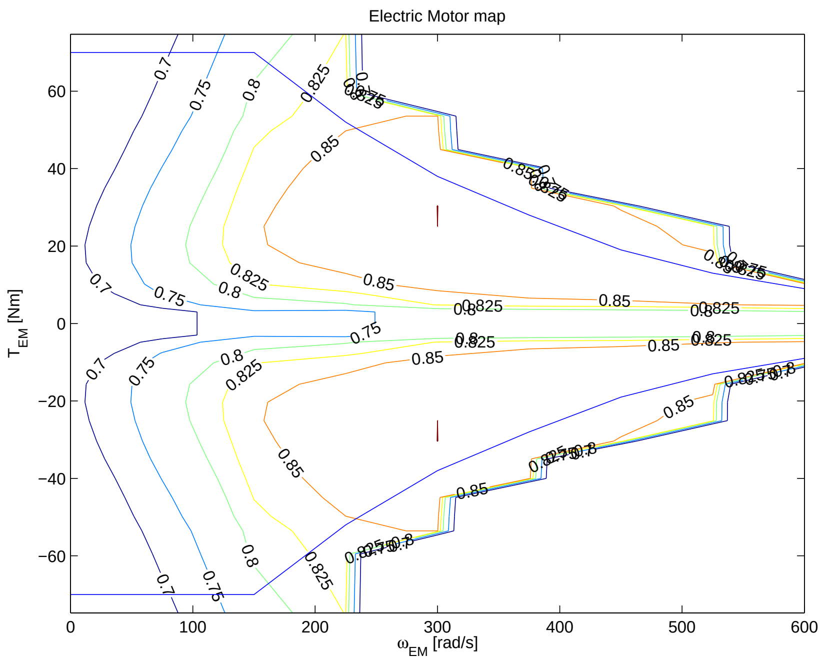

Figure 1: Performace map of electric motor from the QSS library

3.3.2 Electric generator

As with the electric motor assume that the electric generator is of the type from the QSS library. The command *mkPlots.m* is available for download to help you get started with plotting engine performance maps and get an idea of how the efficiency of the electric generator in the QSS library is implemented. In Figure 2 the efficiency map for the electric motor has been plotted together with the torque limit. Assume that the generator is scalable using the scale parameter.

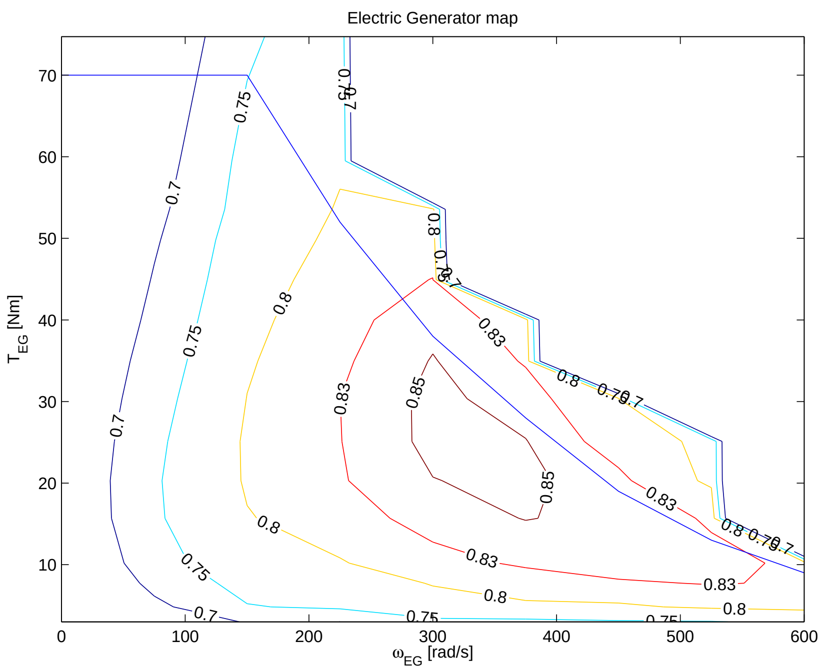

Figure 2: Performace map of electric generator from the QSS library

3.3.3 Combustion engine

Use the Willians approach engine from the course literature. The efficiency of the combustion engine using the Willians approach gives the following equation

$$\eta_{CE} = \frac{bmep}{fuelmep} = \frac{bmep}{bmep + pmep + fmep}\eta_{gas} \tag{2}$$

where $fmep$, $pmep$, $bmep$, η_{gas} is the friction, pump and brake mean effective pressure as well as indicated efficiency from the otto cycle. Here

$$bmep = \frac{4 * \pi * T_{CE}}{V_d}$$
$$pmep = p_{me0g}$$
$$fmep = k_1 * (k_2 + k_3 * (S^2) \cdot (w_{CE}^2))PI\sqrt{(}frack_4B))$$
$$\eta_{CE} = e$$

using the same parameters as in the example file *mkPlots.m*. In Figure 3 the efficiency map for the combustion engine has been plotted together with the torque limit. The torque limit for the combustion engine may be found in the Matlab files `T_CE_max.mat` and `w_CE_max.mat`

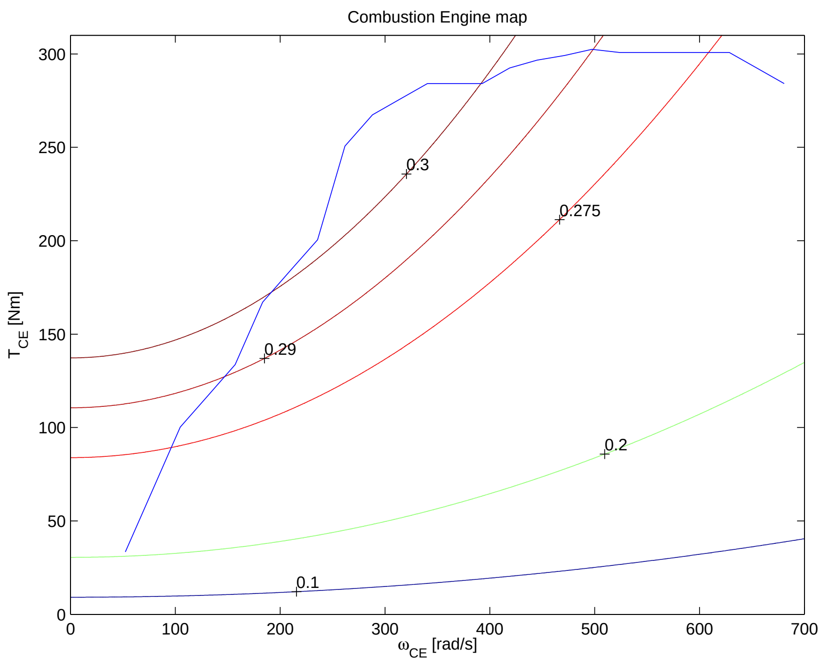

Figure 3: Performace map of combustion engine using the willians approach