SOLUTIONS

METU EE 7566 - Spring 2019

Homework 1: Vehicle Dynamics and Electrified Vehicle Powertrains

Due: 23:59, 7th of April 2019

1. (5 pt.) In a parallel hybrid vehicle, there is a need for mechanical couplers to couple the output of internal combustion engine and electric machine. Name the two main types of coupling devices and give one example for each of them.

   Answer: Torque couplers and speed couplers. A three or two gear gearbox as an example of torque coupler and a planetary gearbox as an example of speed coupler.

2. (5 pt.) Draw the topology of a series hybrid electric vehicle. Name at least two advantages and two disadvantages. What is the most common application of a series hybrid vehicle train?

   Answer: Topology is shown below

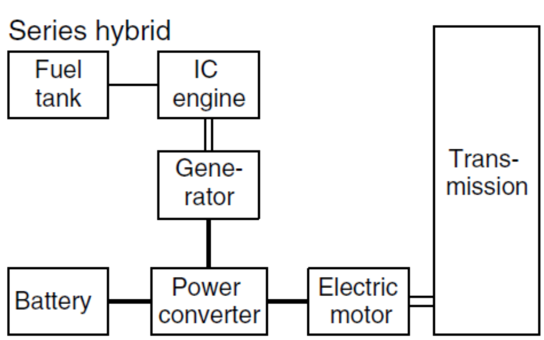
   Advantages:

   - **Easy design**
   - **Internal combustion engine is mechanically decoupled from wheels, it can be designed to have a high efficiency and it can be operated at its best efficiency point.**

   Disadvantages:

   - **Reduced efficiency due to three power conversion stages**
   - **Expensive and heavy since ICE, generator and electric machine need to have close power ratings.**

   Application: Range extender and fuel cell hybrid electric vehicles



3. (5 pt.) Which components are required for an electrical continuous variable transmission (eVT)? What is the motivation of using an eVT?

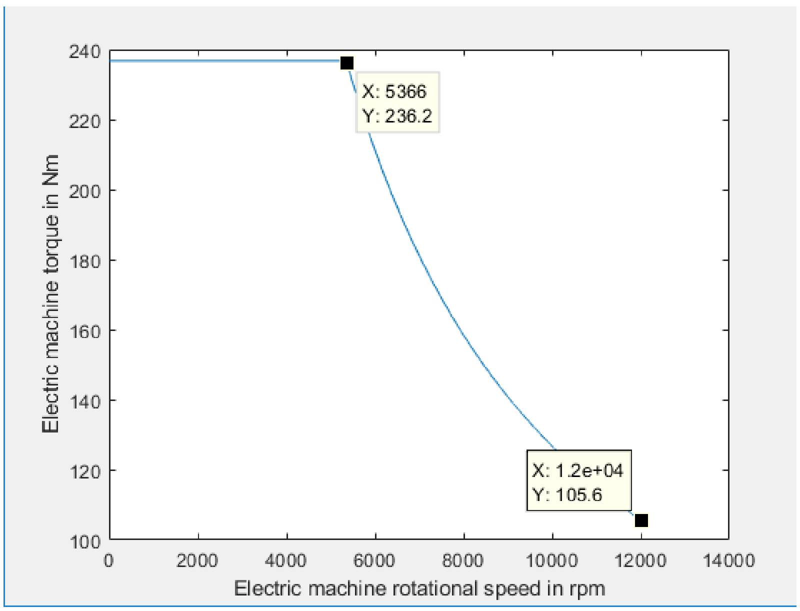
   Answer: A planetary gearbox, an internal combustion engine (ICE), an electric machine (EM) and a battery pack. The ratio of the numbers of sun and ring gears need to be designed according to the speed ratings of ICE and EM.

4. You are asked to redesign a midsize internal combustion engine vehicle (characteristics of the car is given at the end) as a battery electric vehicle with following requirements:
   - Max vehicle speed 150 km/h and acceleration capability at maximum speed 0.05g
   - 0-100 km/h acceleration time in 7.5 sec
   - 350 km for WLTP drive cycle

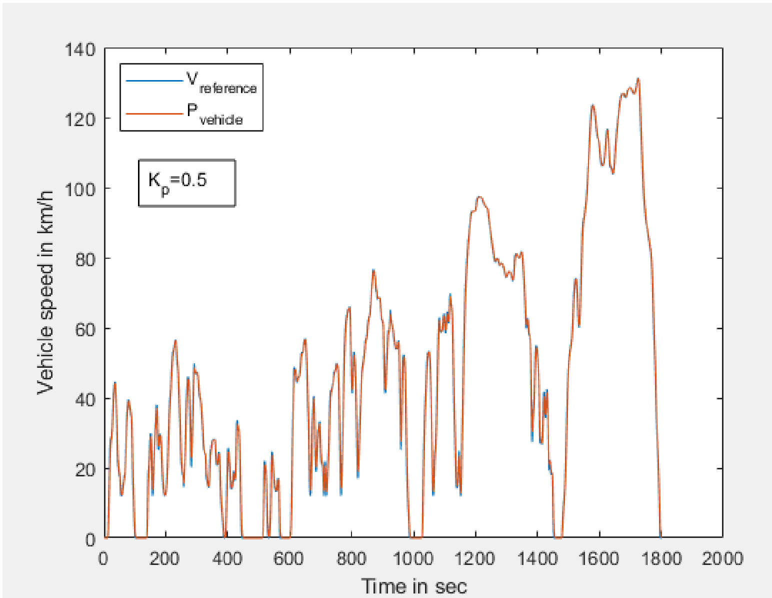
a. (5 pt.) If the maximum speed of the vehicle is limited by the maximum speed of the electric motor, calculate the maximum speed of the electric machine.

Answer: $n_{max} = \frac{150\ x\ G\ x\ 60}{0.3\ x\ 3.6\ x\ (2\pi)}$ **= 12000 rpm**

b. (5 pt.) Draw the characteristic line of electric machine in forward motoring mode. Show and give the values of the maximum speed, maximum torque and base speed.

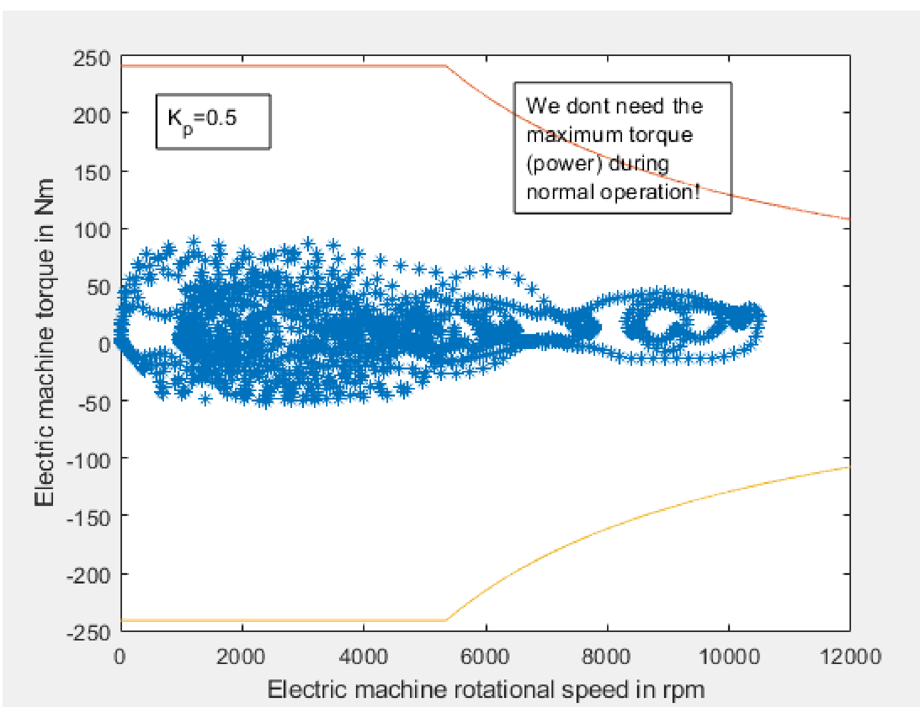


c. (5 pt.) Plot the reference (driving cycle - WLPT) and actual speed of the vehicle. Please give the value of your proportional constant that you used to control vehicle speed. What is the effect of the proportional controller on speed output and fuel economy? Do cars have different variable controller values? If yes, what is its application?



Answer: K_p determines the traction force (or power) of the car for a given gas pedal position. So, this value changes the driving mode. K_p in eco mode is lower than K_p in sport mode.

d. (5 pt.) Plot the operating points of the electric machine for the given driving cycle (Points on torque speed characteristics).



e. (10 pt.) Calculate the consumption and economy of this BEV car in kWh/km and TL/km, assume a constant efficiency of 98% for the charger and 0.5 TL/kWh of electricity price.

K_p	Consumption	Fuel economy
0.5	0.13961 kWh/km	0.07 TL/km

f. (10 pt.) What is percentage of regenerative braking energy that is recuperated brake energy over tractive energy for cruising and acceleration? Comment on importance of regenerative braking. In which driving pattern it is more crucial, city or highway driving?

K_p	Regenerated energy/Energy required for acceleration and cruising
0.5	17.748 %

g. (10 pt.) Fill the table with your previous results. Repeat the calculations for the following cases:

- 350 km range + acceleration at maximum speed 0.05g and power requirement of accessories is equal to 0 W.
- 500 km range + acceleration at maximum speed 0.05g and power requirement of accessories is equal to 750 W.
- 500 km range + acceleration at maximum speed 0.05g and power requirement of accessories is equal to 0 W.

5. Your company wants to design a range extender version of the electric vehicle in question 4 with a total range of 500 km (Powertrain components you designed in question 4 for 350 km range are kept the same). Select an ICE power output and capacity of the fuel tank. Assume a constant efficiency of 35% for the ICE. (**The power of ICE** needs to be equal to electric machine power in a series HEV but **in a range extender it has to be the average power consumption**, please also consider that you also need to add a generator)
   a. (10 pt.) Calculate the mixed fuel consumption and fuel economy of this car in WLTP in kWh and TL/km, assume a constant efficiency of 98% for the charger and 0.5 TL/kWh of electricity and 6.25 TL/l of gasoline (take gasoline energy density as 9700 Wh per liter)
   b. (10 pt.) Fill the table following table by changing variables as explained in question 4.

See the table!

6. Compare all of electric vehicles designed so far.
   a. (5 pt.) Which of the electric cars with 500 km range would you favor? Why?

      Answer: When we compare the BEV with 500 km range with REX with 500 km range, obviously BEV is heavier and more expensive but it has a much better fuel economy and it is free of local pollutions. I would select REX because in our daily life we don't need 500 km range. Since 350 km is more than enough for me, I would benefit from the good efficiency of this car in electrical driving and feel free to drive long distances when required.

b. (5 pt.) Comment on effect of electric machine power on the consumption and car performance.

Answer: Electric machine power is important mainly at high speed driving and full gas acceleration. Other than that, we usually use the electric machine around 25 % torque region. If electric machine has a higher power capability, performance of car increases but it does not affect fuel economy significantly excluding the increase in vehicles mass.

c. (5 pt.) Calculate the charging durations of the battery in question 5 with Level 1 & 2 charging.

Level	Charger Location	V/amps	Electricity Delivered (kW)
1	On board	120/15	1.8
2	On board	240/80	19.2
3	Off board	480/max 200	max 90

	Charging duration
Level 1	**42.814**/1.8=23.78 h
Level 2	**42.814**/19.2=2.22 h

Please submit the code with your homework.

Good Luck!

		Capacity of battery In kWh	Electric machine power in kW	Electric machine torque in Nm	Mass of drivetrain in kg (incl. battery)	Cost of drivetrain in $	Fuel consumption in kWh	Fuel economy In TL/km	Total Regen. energy in %
BEV with 350 km range	0.05g & 750 W	**48.862**	**135.03**	**241.08**	**1599.3 – 70kg**	**16242**	**0.13961**	**0.071228**	**17.748**
	0.05 g & 0 W	**42.486**	**132.28**	**235.87**	**1564.7 – 70kg**	**14833**	**0.12139**	**0.061934**	**17.513**
BEV with 500 km range	0.05g & 750 W	**72.072**	**145.03**	**260.05**	**1725.2-70 kg**	**21333**	**0.14414**	**0.073542**	**18.535**
	0.05 g & 0 W	**62.665**	**140.97**	**252.35**	**1674.1-70kg**	**19259**	**0.12533**	**0.063944**	**18.218**
BEV REX with 350+150 km range	0.05g & 750 W	**49.228**	**137.34**	**245.46**	**1628.3-70 kg**	**17000**	**0.60045**	**0.36802**	**17.936**
	0.05 g & 0 W	**42.814**	**134.32**	**239.78**	**1590.6-70 kg**	**15495**	**0.52221**	**0.32007**	**17.685**

Vehicle and component characteristics:

Mass of body without powertrain	1000 kg
Increase in mass due to acceleration of rotating masses	1.05
Gravitational acceleration	9.8 m/s^2
Frontal area	2.57 m^2
Aerodynamic drag coefficient	0.26
Density of air	1.25 kg/m^3
Friction coefficient of tires	0.006
Radius of wheels	0.3 m
Gear ratio (electric motor to wheels	9.0478
Accessories consumption (fixed)	750 W
Adhesive coefficient of tires to ground surface	0.9
Front wheel drive with equally distributed load on wheels	0.5 (Acceleration)
Load distribution during braking, W_{front}/W_{total}	0.65 (Braking)
Specific cost of electric machine + inverter	$30/kWh
Specific mass of electric machine + inverter	1.1 kW/kg
Specific volume of electric machine + inverter	2.6 kW/l
Battery pack specific cost, P_{batt}/E_{batt}: power-to-energy ratio	**$(200 + 13 x P_{batt}/E_{batt})/kWh**
Battery pack specific mass	**(200 - 3 x P_{batt}/E_{batt}) Wh/kg +120 kg**
Specific cost of internal combustion engine	$50/kW
Specific mass of internal combustion engine	0.55 kW/kg
Charger mass and cost (fixed)	10 kg and $300
Fuel tank mass and cost (fixed)	5 kg and $150

Assume following constant efficiency values for the energy converters.

Efficiency of electric machine + inverter	*92%*
Efficiency of gearbox + differential	*97%*
Efficiency of battery pack	*95%*