Selecting an All-Electric Vehicle Powertrain

1   Introduction

The calculations of this assignment will be done using Matlab, which is a powerful numerical computing environment. You can install Matlab on your own computer: the software and its activation key are available at `download.aalto.fi`. This assignment aims to familiarise you with basic features of Matlab.

This assignment deals with selection of drive components (an electric traction motor and a power-electronic converter) for an all-electric vehicle powertrain. The powertrain components will be selected based on the New European Driving Cycle (NEDC), which has been traditionally applied to assess the emission levels of car engines and fuel economy in passenger cars. After this assignment, you should be able to

1. Use Matlab for basic mathematical calculations.
2. Apply the motion equation to define the driving cycle.
3. Calculate the effective torque of an electric motor based on the driving cycle.
4. Select a suitable motor and a converter for a given application.

A report is to be written on this assignment in groups of two (or alone). Submit your report as a pdf file to the MyCourses portal no later than on *Wednesday, 21.10.2020, at 16:00*. In your report, answer *briefly* the numbered questions given inside this kind of framed boxes. The report should be clearly and consistently written. *Please include every plotted figure in the report.* Submit also the Matlab script, which you used to calculate the results for each of the questions. Guidance is available at the Teams platform on

- Wednesday, 30.9.2020, at 10:15–12:00
- Wednesday, 14.10.2020, at 10:15–12:00

The assignment will be graded on a scale of $0 \ldots 10$ (one point per problem). You are encouraged to discuss with other students but copying solutions from other groups is not allowed! The reports and models will be checked for plagiarism.

Note: The component selection based only on the NEDC is a simplified approach and may not be directly used in real-life design cases.

2 Studied Vehicle

2.1 Dynamic Model

In the following, the vehicle longitudinal-dynamics model is introduced. According to Fig. 1, the differential equation describing the motion dynamics of the vehicle can be derived from the Newton second law as

$$m\frac{\mathrm{d}v}{\mathrm{d}t} = F_\mathrm{w} - F_\mathrm{d} \tag{1}$$

where m is the mass of the vehicle, $\mathrm{d}v/\mathrm{d}t$ is the longitudinal acceleration of the vehicle, F_w is the accelerating force generated by the driving wheels, and F_d is the force that resists the motion. The resistive force F_d depends on the forward velocity v and it can be modeled as

$$F_\mathrm{d} = C_\mathrm{d}v^2 + C_\mathrm{r}mg \cdot \mathrm{sign}(v) \tag{2}$$

where C_d is the drag coefficient and C_r is the rolling-resistance coefficient. Since the driving cycle (v and $\mathrm{d}v/\mathrm{d}t$) and the vehicle-model parameters (cf. Table 1) are known, the force F_w required from the driving wheels can be calculated using (1) and (2).
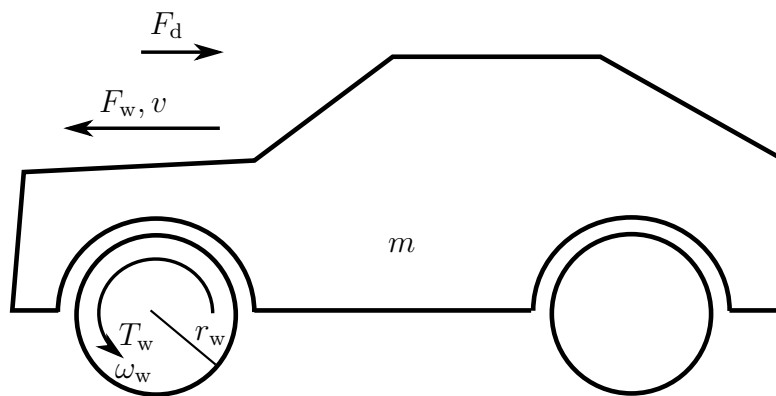

Figure 1: Vehicle model.

Table 1: Vehicle-model parameters.

Mass of the chassis m	1 500 kg
Radius of the driving wheels r_w	0.295 m
Reduction-gear ratio i	8
Drag coefficient C_d	0.65 kg/m
Rolling-resistance coefficient C_r	0.015
Gravitational acceleration g	9.81 m/s^2

2.2 New European Driving Cycle Velocity Profile

The traction motor and the converter for the vehicle will be selected based on the New European Driving Cycle. Furthermore, the maximum performance of the motor is selected based on the required top speed and 0–100 km/h acceleration performance. In the NEDC, the velocity of the vehicle v changes as a function of time as shown in Fig. 2. The profile lasts 1 180 seconds.
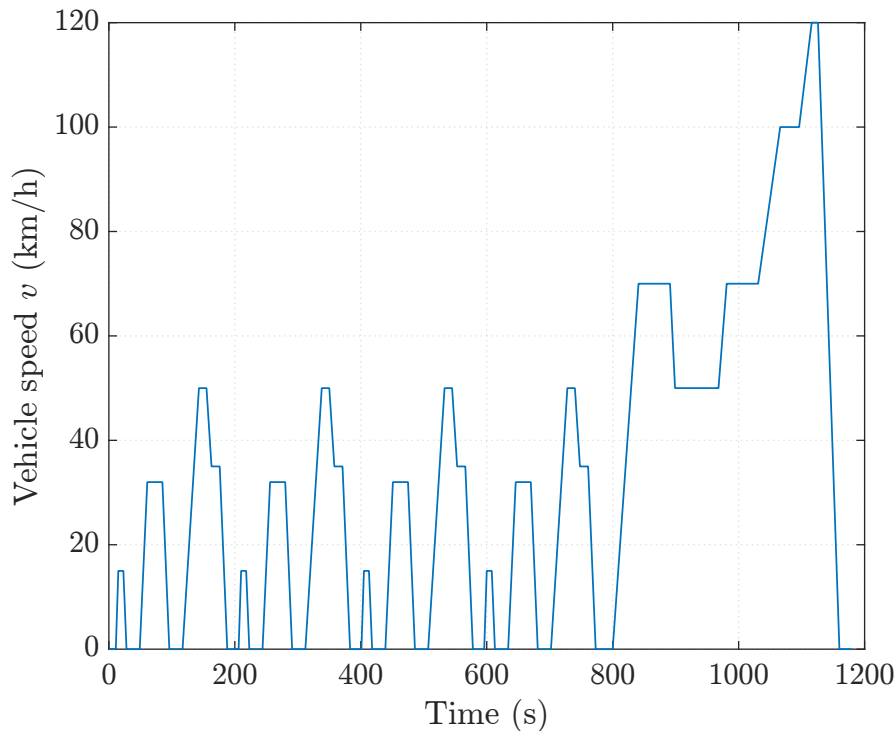
Figure 2: New European Driving Cycle (NEDC) velocity profile.

Download the data file `NEDC.mat`, containing the NEDC profile, from the MyCourses portal. It is recommended to start using Matlab scripts to complete the questions of this assignment. To open a blank script in Matlab, press the button New Script, located on the upper left-hand corner of your Matlab command window. Save the script file using your preferred file name (e.g., `assignment1.m`). You can then run the script from the Matlab workspace by typing its name (`assignment1`).

Some useful Matlab commands for figure plotting, data handling, and basic mathematical calculations are listed below:

```matlab
% In the beginning of scripts, the following commands are useful
close all    % Closes all the open figures
clc          % Empty the command window

% Load a data file data_file.mat into the Matlab workspace
load('data_file.mat')
% After loading the data file, you can type Matlab command whos to see
% the names and the types of data located in your workspace

% Handling time-series data, i.e. y = y(t), in Matlab
% Name of the time series data package: example
% Time t values
t = example.Time;
% Data y values
y = example.Data;

% Plot the data in xy-coordinates
plot(t,y);
grid on;             % Set the background grid on
xlabel('Time (s)'); % Set the x-axis label
ylabel('y');         % Set the y-axis label
```

```
% The following commands can be used to calculate basic mathematical
% operations between two signals (named in this example as x and y)

% To calculate the sum of x and y, type
sum_xy = x + y;
% To divide x by y, type
div_xy = x./y;
% To calculate the product of x and y, type
prod_xy = x.*y;
% To calculate a power function x^(n), where n is an arbitrary power
pow_n_x = x.^n;
% To calculate square root of x
sq_x = sqrt(x);
% To calculate absolute value of x
abs_x = abs(x);
% To calculate the signum function of x
sgn_x = sign(x);
```

1. Open Matlab and create a script that loads the downloaded datafile `NEDC.mat` into the Matlab workspace and then plots the NEDC velocity profile v (cf. Fig. 2). Include the figure in your report. You can use the Matlab command `whos` to sort out the name of the time-series variable inside the loaded datafile.

2.3   Acceleration and Wheel Force of the Vehicle

As can be seen in (1), also the longitudinal acceleration $\mathrm{d}v/\mathrm{d}t$ is needed in order to calculate the required wheel force. Below is an example how to numerically calculate the derivative $y'(x) = \mathrm{d}y(x)/\mathrm{d}x$ of an arbitrary signal $y(x)$, when both the signals $y(x)$ and x are known.

```
% Calculate the number of samples in the signal vector x
N = length(x);

% Calculate the acceleration
for k = 1:N-1
    dyx(k) = (y(k+1)-y(k))/(x(k+1)-x(k));
end

% Adding an extra zero in the end to make dyx the same length as y and x
dyx = [dyx 0];
```

2. Calculate the longitudinal acceleration $\mathrm{d}v/\mathrm{d}t$ of the vehicle based on the NEDC velocity profile v. You may use the previously listed example to complete this task. Then, plot the obtained acceleration profile as a function of time t.
3. Use (1) together with the velocity v and the acceleration profile $\mathrm{d}v/\mathrm{d}t$ to define the required wheel force F_{w} as a function of time. Plot the result.

2.4   Maximum Performance

The maximum performance of the vehicle is defined based on the required top speed of the vehicle v_{max} and the required 0–100 km/h acceleration time t_{100}. These values are given in Table 2.

Table 2: Performance specifications.

|	
Top speed v_{max}	150 km/h
0–100 km/h acceleration time t_{100}	8 s

4. Based on the values given in Table 2, calculate the maximum torque $T_{\mathrm{w,max}}$ and the maximum rotational speed $\omega_{\mathrm{w,max}}$ required from the driving wheels. For simplicity, assume a constant motion resistive force $F_{\mathrm{d}} = 500$ N in this task.

3   Traction Motor

In the following, the results of Section 2 will be used to define the properties of the traction motor. The driving wheels are connected to the traction motor using a reduction gear, i.e., the angular speed of the motor shaft is higher than the angular speed of the wheels. The reduction-gear ratio is given in Table 1. Furthermore, the motor and wheel inertias are negligible as compared to the load inertia caused by the mass of the vehicle.

3.1   Speed and Torque of the Motor
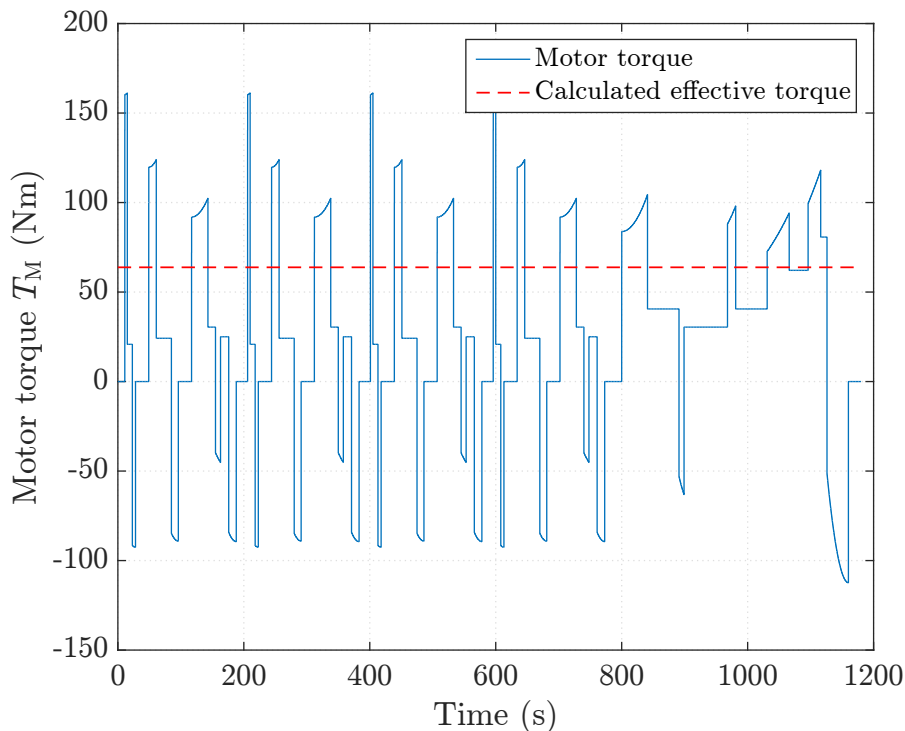
Figure 3: Motor torque (solid blue line) and the calculated effective torque (dashed red line) in an example case. It is to be noted that the calculated effective torque is not directly the root-mean-square value of the motor torque, because the motor is operating both in the full-field region and in the field-weakening region in this example (cf. Section 3.3).

5. Use the velocity profile (given in Section 2.2) and calculate the motor speed ω_{M} as a function of time. Plot the result.
6. Furthermore, use the wheel force F_{w} (defined in Section 2.3) to calculate the motor torque T_{M} as a function of time. Plot the result. As an example, the motor torque (with an undefined reduction-gear ratio) is shown in Fig 3. Then, calculate the required mechanical power p_{M} as a function of time and plot the result.

3.2   Maximum Performance

7. Use the values defined in Section 2.4 and calculate the maximum torque $T_{\mathrm{M,max}}$ and maximum speed $\omega_{\mathrm{M,max}}$ required from the traction motor.

3.3   Effective Torque of the Motor

If the traction motor operates in the full-field region (i.e., when $|\omega_{\mathrm{M}}| \le \omega_{\mathrm{N}}$) at $t = 0 \dots t_1$, and in the field-weakening region (i.e., when $|\omega_{\mathrm{M}}| > \omega_{\mathrm{N}}$) at $t = t_1 \dots t_{\mathrm{c}}$, then the effective torque of the motor is defined as

$$T_{\mathrm{M,ef}} = \sqrt{\frac{1}{t_{\mathrm{c}}} \int_0^{t_1} T_{\mathrm{M}}^2 dt + \frac{1}{t_{\mathrm{c}}} \frac{1}{\omega_{\mathrm{N}}^2} \int_{t_1}^{t_{\mathrm{c}}} p_{\mathrm{M}}^2 dt} \tag{3}$$

where t_{c} is the total length of the driving cycle. Below is an example how to numerically calculate the effective torque (3) using Matlab.

```matlab
% Number of samples in the motor-torque data vector TM
N = length(TM);

% Drive-cycle end time tc
tc = t(end);

% Calculate the value inside the integrals in (3) at each time instant k
for k = 1:N
    if abs(wM(k)) < wN
        % When the motor operates in full-field region
        TI(k) = TM(k)^2;
    else
        % When the motor operates in field-weakening region
        TI(k) = PM(k)^2/wN^2;
    end
end

% Numerical integration can be completed in Matlab using trapz command
TM_ef = sqrt(trapz(t,TI)/tc)
```

8. Calculate the effective torque of the traction motor based on the torque and power cycles defined in Section 3.1. The nominal speed of the motor can be assumed to be $n_{\mathrm{N}} = 4\,000$ r/min.

4 Motor and Converter Selection

Here, the traction motor of the vehicle will be selected based on the results calculated in Section 3. Finally, the frequency converter will also be selected.

9. Select a suitable traction motor from the motor list (available at the MyCourses portal). Pay attention to the nominal torque, the maximum rotational speed, and the maximum torque. Explain briefly how you selected the motor.
10. Select a suitable converter for the motor from the converter list. Explain briefly your selection.

Give Us Feedback

In order to improve this assignment, please give us feedback. In order to estimate the student workload, we would also be happy to know how many hours did you use to do this assingment. All other comments are also welcome.