# Assignment 2 – Vehicle dynamics

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### Introduction

In this report, we are going to analyse the implementation and simulation of a rear-wheel-drive electric passenger car in MATLAB and Simulink. The target of the work is to develop a model of a vehicle motion and carry out tests of different cases, related to the main elements that are involved in the longitudinal dynamics (acceleration, friction braking, energy consumption, regenerative braking)

As a case study vehicle was given in the assignment, a set of parameters was already provided in *Table 1* and, whenever required, reasonable assumptions were made in order to obtain a complete and consistent description of the vehicle.

Table 1 - Main vehicle parameters

|  |  |
| --- | --- |
| E. machine peak power | 150 kW |
| E. machine maximum torque | 310 Nm |
| E. machine maximum speed | 16000 rpm |
| Gear ratio | 10.5 |
| Usable battery capacity | 58 kWh |
| F-to-R friction brake torque distribution | 75:25 |
| Kerb weight | 1812 kg |
| Wheelbase | 2.77 m |
| F-to-R mass distribution | 50:50 |
| Frontal area | 2.36 m^2 |
| Aerodynamic drag coefficient | 0.27 |

### Description of the model

The overall model consists of multiple subsystems, each one of them modelling different aspects of the vehicle.

#### Wheels

4 independent wheels, which share a common referenced model *wheel\_model.slx*, take as inputs the vertical load, friction coefficient, velocity of the vehicle and applied motor and braking (due to dissipative brakes) torques.

According to the Pacejka 96 tyre model, forces are computed and, in our case study, only the longitudinal component is used in next steps.

A second subsystem, regarding wheel dynamics, applies the moment balance equation, which considers torque given from the motor, friction brakes, rolling resistance and longitudinal force, in order to compute the angular acceleration and speed.

Tyre longitudinal slip is computed as a function of the vehicle speed and the obtained angular speed, it can fed either directly to the Pacejka function or to a subsystem which models tyre relaxation and computes a delayed slip ratio based on a mass-damper first order dynamics similarity, based on values set in the script.

ABS??

#### Longitudinal dynamics

Acceleration and speed at the center of gravity are computed based on the force balance equation, which considers the total longitudinal force, aerodynamic drag, gravity (due to possible inclination, but always set to 0 in our examination) and rolling forces.

As some of the formulas hold only for non-negative speeds, a saturation block is used.

#### Power losses

In the model some power losses are firstly computed and then integrated to obtain the energy losses of rolling resistance, aerodynamic drag, powertrain, transmission and longitudinal slip.

#### Vertical load distribution

The computation of vertical force *Fz* for each wheel takes into account also load transfers due to aerodynamic drag and non-zero acceleration while it neglects the aerodynamic downforce and the rolling resistance parameter Dx which shifts the application point of Fzr and Fzf as it was considered negligible in prior simulations.

#### Electric machine

In the first part of the subsystem, we computed the motor speed as a function of the vehicle speed, gear ratio and wheel radius. Then, a MATLAB function computes the maximum available torque that can be produced at a given motor speed. This default behaviour can be modified by test cases in which we’re interested in specific torque profiles, while preserving the torque/speed characteristic of the electric motor.

Furthermore, a transfer function was added in order to model a realistic motor with a given torque generation time constant.

#### Battery

To manage the current available energy, we decided to work in terms of Wh. The available energy from the battery is computed starting from an initial State of Charge (SoC) and the nominal capacity. It is then modified during the simulations based on the energy requested or given from the Electric Motor, after taking into account the efficiency of motor and inverter. It has to be noticed that the implemented mechanism can also manage recovered energy obtained during regenerative braking in a consistent way. The SoC is updated at each time step.

#### Braking System

Our friction braking system consists of 4 individually controlled brakes with a fixed front-to-rear brake torque distribution.

To compute the total braking force, we first compute the force for the front wheels by taking into account the vertical force of the front Fzf, a specific friction coefficient μ and the current position of the brake pedal, that we normalized in [0;1] interval. The rear braking force is then derived from the front one and the fixed distribution. The output of the subsystem is a braking torque Tb (defined as positive) which goes to the corresponding wheel model.

A first-order transfer function, also in this case, was added in order to simulate a realistic behaviour of the braking system.

### Tests

The previously mentioned model was used to simulate the vehicle motion in a set of use cases which are acceleration tests, range tests and braking tests with regenerative and dissipative brakes.

#### Longitudinal acceleration test

In this test, executed in high tyre-road friction conditions, we analysed the vehicle behaviour in cases in which we are interested in reaching certain speeds starting from a given one.

|  |  |
| --- | --- |
| Immagine che contiene testo, linea, Diagramma, diagramma  Descrizione generata automaticamente  0-50 Km/h | 0-100 Km/h |
| 40-70 Km/h | 80-120 Km/h |
|  |  |

Figure 1 - Acceleration and speed profiles in acceleration tests.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| E loss  [Wh] Test [km/h] | Aero Drag | Long Slip | Ptrain | Roll Res | Transm |
| 0-50 | 0.22 | 5.27 | 6.00 | 0.89 | 2.70 |
| 0-100 | 5.16 | 14.24 | 25.04 | 5.77 | 11.27 |
| 40-70 | 0.81 | 5.37 | 8.04 | 1.43 | 3.62 |
| 80-120 | 11.88 | 5.62 | 21.95 | 8.88 | 9.88 |
| 0-*top\_speed* | 211.72 | 29.76 | 130.40 | 107.30 | 58.68 |

The results of the simulations, in this set of relevant acceleration tests, show realistic behaviour of the vehicle, with characteristics such as the responsiveness typical of a rear-wheel drive electric passenger car. The acceleration has a nearly constant profile; however, it is possible to see oscillations, especially when starting from zero speed, due to the modelling of tyre relaxation. The speed, as expected, shows a linear behaviour which is visible in the Fig. 1a and 1c, and becomes more complex as the speed increases, along with aerodynamic drag, which can be seen in Fig 1b and 1d.

Table 2 - Relevant acceleration times

|  |  |
| --- | --- |
| Considered tests | Time |
| 0-50 Km/h | 3.10 s |
| 0-100 Km/h | 7.25 s |
| 40-70 Km/h | 1.95 s |
| 80-120 Km/h | 4.75 s |

One of the aspects we considered is the energy loss accumulated during our tests. For each test, we calculated some of the main power losses associated with aerodynamic drag, longitudinal tyre slip, powertrain, rolling resistance, and transmission. Our results are presented in Table 3.

As we expected, in tests in which the vehicle reaches high speed, the contribution of the aerodynamic drag increases, in particular in “0-*top\_speed*” test case where it has the highest value. Furthermore, in the same instances, its

Table 3 – Energy Losses

contribution quickly exceeds the one given from rolling resistance. Additionally, the powertrain power loss is a relevant element to the overall consumption of the vehicle. In particular, it depends linearly on the power provided by the electric motor when the requested torque is at its maximum, up to the point in which the peak power is reached. Once the power reaches its peak, the powertrain power loss no longer increases linearly but it remains at the same value for every following time step. In addition, we can notice a similar behaviour for the transmission power loss, but with a minor contribution.

An instance of power losses behaviour is shown in Figure 2.

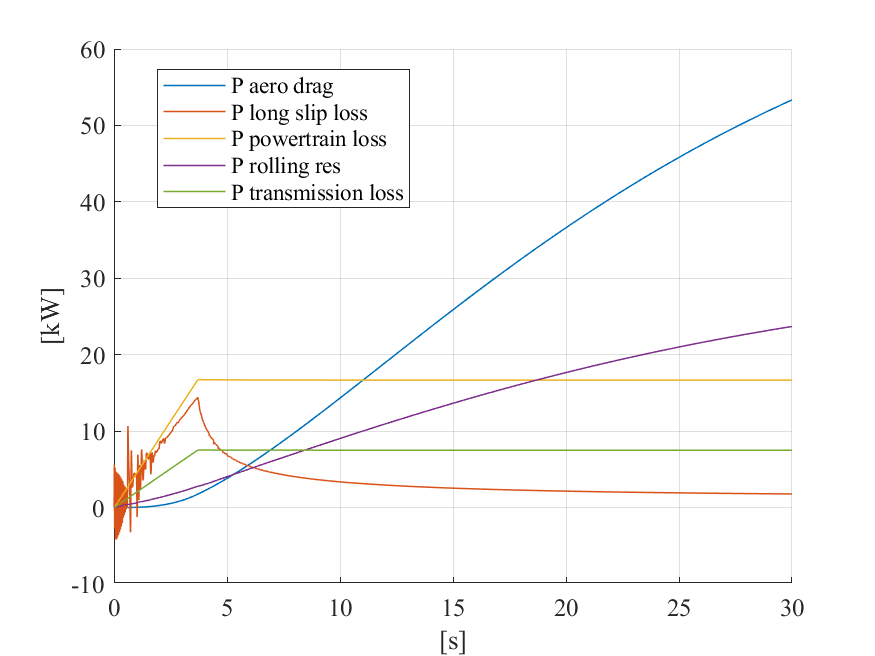


Figure 2 – Power losses in 0-top\_speed test

#### Energy consumption and achievable range at different constant speeds

In the following test case, we tracked the energy consumption and achievable range during vehicle motion at different constant speed (low, medium and high).

// Figure of consumptions in diff cases

Analysing the rolling resistance loss in different cases, we can notice that it is progressively reduced when the vehicle is at constant high speed. Anyway, it always gives a significant contribution to the overall energy consumption.  
In low speed constant test cases, the loss is higher because of the major covered distance.

On the other hand, aerodynamic drag loss increases significantly at higher vehicle speeds and becomes the most substantial cause of energy loss. The longitudinal tyre slip loss, in a similar way, increases in relation with the vehicle speed.

We can also notice that the electric powertrain and transmission losses remain constant in every test case due to the motor engine which provides the same power that does not change in time at same speed.

At the end of all tests, we can ascertain that the overall energy consumption is more efficient when the vehicle is at low/medium speed. However, in high speed conditions, the efficiency drastically decreases due to the exponential increase of the rolling resistance contribution.

#### Tip-in and tip-off tests