

TECHNOLOGIES FOR AUTONOMOUS VEHICLES

VEHICLE DYNAMICS

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Case study vehicle

- A car maker has asked a small consultancy firm to carry out some preliminary simulations of the expected longitudinal performance of a new **rear-wheel-drive electric passenger car**
- The expectation is that the model considers the **longitudinal motion of the vehicle body, front and rear wheel rotations, and the wheel slip, electric powertrain, and friction brake dynamics**, including the effect of the **longitudinal load transfers** in acceleration and deceleration
 - angular wh. speed
 - w. tire relaxation
 - effect of F_z
- The vehicle has a **single electric machine** with **150 kW peak power**, **310 Nm maximum torque**, and **16,000 rpm maximum speed**
- The car is characterised by a **single-speed transmission** with an overall **10.5:1 gear ratio**, and an **open differential**
 - 50:50 torque equally distributed among axle
 - torque at wheel is 10.5 torque at the motor (or viceversa ??)
- The **pure time delay** (between torque request and motor current variation) **of the electric powertrain amounts to 20 ms**, while the motor torque generation **time constant is 50 ms**
 - accel. pedal -> 20 ms -> motor "changes"
 -

Case study vehicle

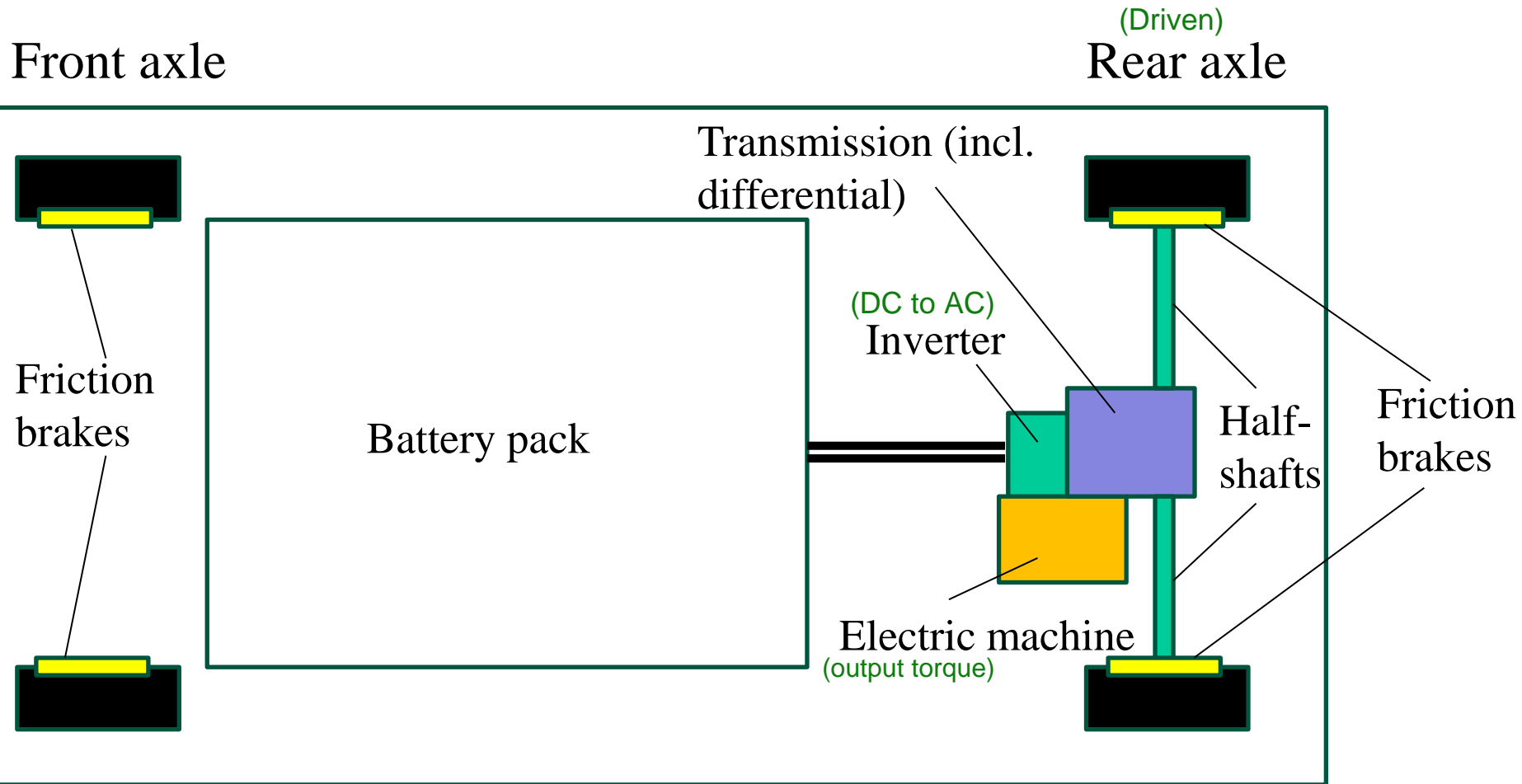
- The **efficiency of the electric motor and inverter** can be assumed to be **0.90** for both traction and regeneration
- The **mechanical transmission efficiency** can be assumed to be **0.95** for both traction and regeneration
- The **torsional stiffness** of each half-shaft is **9000 Nm/rad** } (opt. ?)
- The usable **battery capacity** is **58 kWh**
- The **nominal battery voltage** is **800V**
- The tyres are **215/50R19**, ^{-> computation of wheel radius} and their **magic formula coefficients** (version 96) are provided in the **attached file** (Tyre_215_50_19.m), together with the magic formula implementation
- The values of the **tyre rolling resistance coefficients** are **0.009** (term independent from the vehicle speed) and **$6.5 \times 10^{-6} \text{ s}^2/\text{m}^2$** (term to be multiplied by the vehicle speed squared)
- ^{assumption}
 - **Reasonable tyre relaxation parameters** should be considered, including their variation as a function of the operating condition of the tyre

Case study vehicle

- The **friction brakes** are electro-hydraulic and are seamlessly and **individually controlled**
- The **pressure** – and thus torque – **generation deadtime of the friction brakes** is **20 ms**, while the **rise time** is **25 ms¹** (Lecture shows figures 3, 4 in paper #6)
- The **static front-to-rear friction brake torque distribution** is **75:25** (for the same pressure level on the front and rear axles)
- The **kerb weight** is **1812 kg**, the **wheelbase** is **2.77 m**, and the **centre of gravity height** is **0.55 m**
- In the same conditions, the **front-to-rear mass distribution** is **50:50**
- The **vehicle frontal area** and **aerodynamic drag coefficient** can be assumed to be **2.36 m²** and **0.27**
- All the other parameters and characteristics can be based on **reasonable assumptions** (and/or found online, etc)

¹D. Tavernini et al., "An Explicit Nonlinear Model Predictive ABS Controller for Electro-Hydraulic Braking Systems," in IEEE Transactions on Industrial Electronics, vol. 67, no. 5, pp. 3990-4001, May 2020, doi: 10.1109/TIE.2019.2916387.

Case study vehicle



ex. 100 Nm generated by electric machine $\rightarrow 100 \cdot 10.5 \cdot \text{efficiency}$ total torque (we further divide by 2 to obtain torque at single wheel)

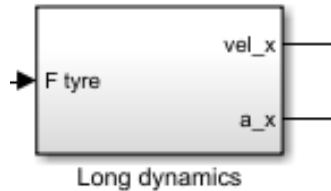
Efficiency instead of the ELECTRIC machine to be considered if plotting electrical power from battery to inverter

Mechanical power gener. by el. machine = torque * angular motor speed

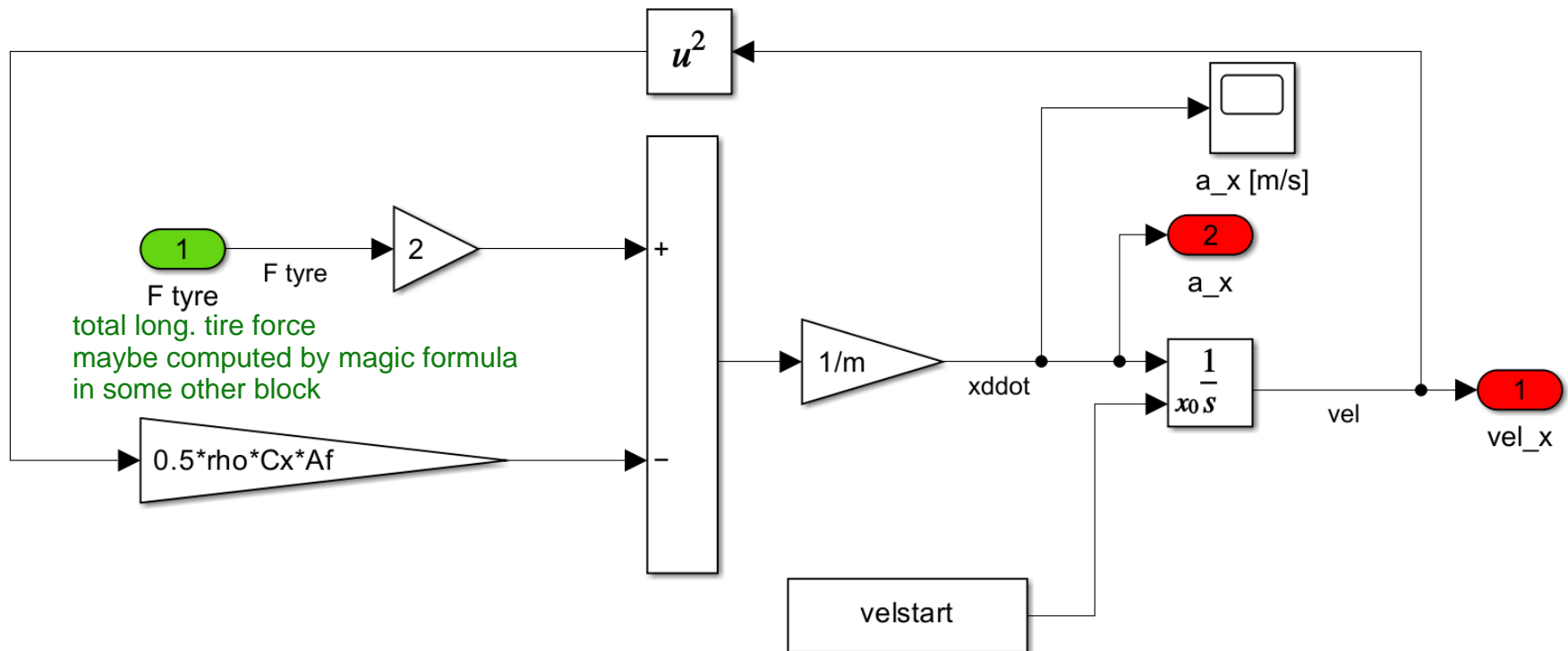
Battery power = el.machine power / efficiency of inverter and electric machine

Homework – Section 2

Expected outputs – the vehicle model



- Vehicle subjected to longitudinal tyre forces
- Vehicle subjected to aerodynamic drag



Homework – Section 2

"total" model should contain long dynamics, many wheel dynamics, slip ratio, tire model

Either 4 wheels or simpler model with 1 wheel per axle
Expected outputs – the vehicle model

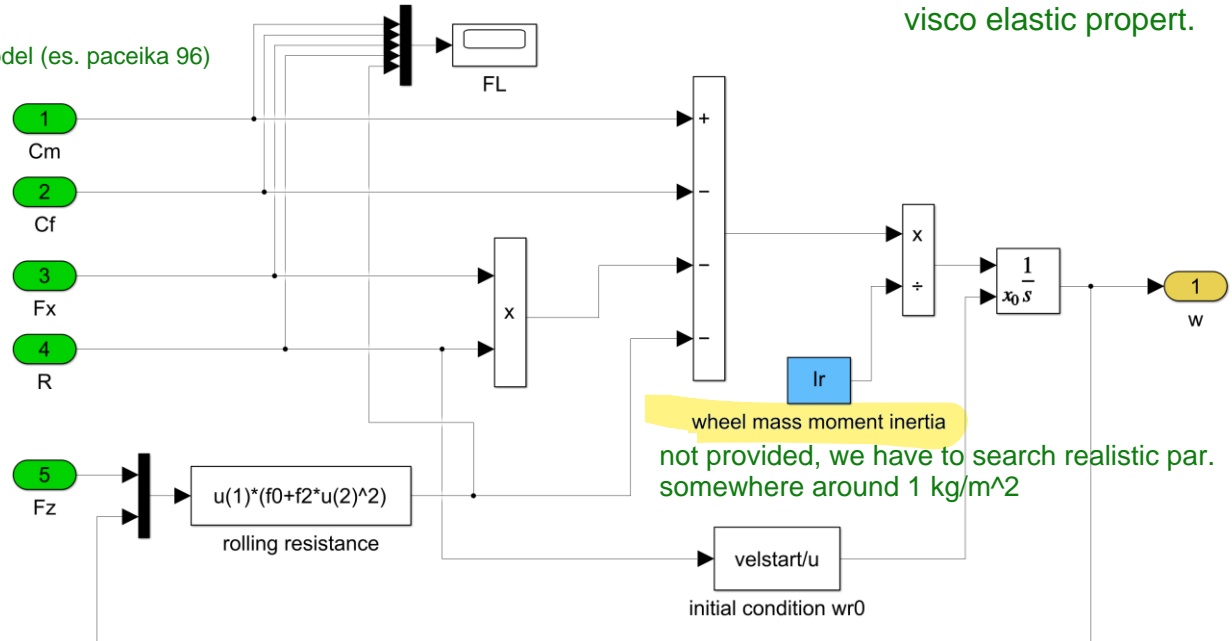
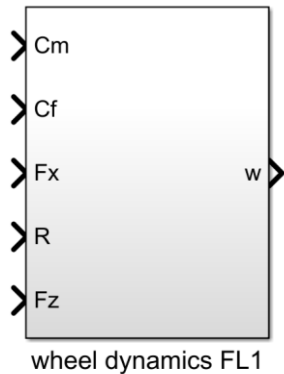
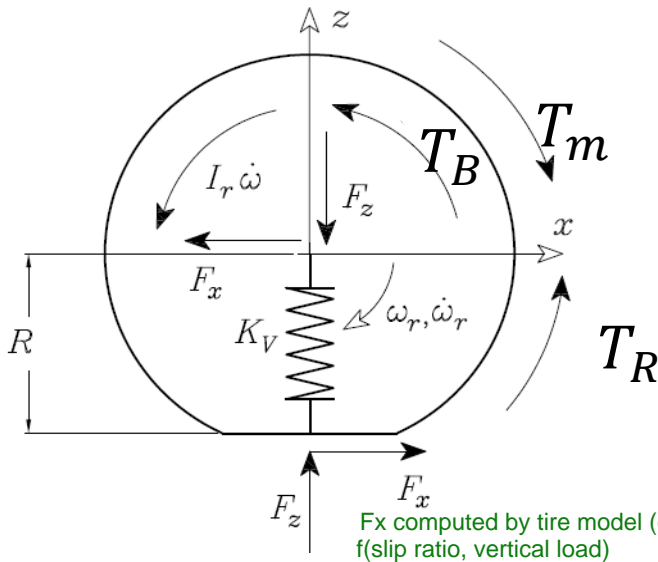
Rotational wheel dynamics

T_m motor torque ref. to wheel (considered differential, transm. ratio, etc)

$$\dot{\omega}_r = \frac{T_m - T_B - T_R - F_x R}{I_r}$$

ang. accl. of each wheel

visco elastic propert.



Homework – Section 2

Expected outputs – the simulations

(result: acceleration and speed profile, table with acceleration times like 0-100, etc..) (If wheel spinning, we can emulate simple traction control which saturates motor torque)

- Simulation of a **longitudinal acceleration test** in high tyre-road friction conditions, with potential consideration of the intervention of the traction control system



- Computation of the relevant **acceleration times**

Would be nice?

$r. \text{ resist. torque} * \text{wheel speed}$

- Computation of the **rolling resistance, aerodynamic drag, electric powertrain, transmission and longitudinal tyre slip power losses** during the same test

$\text{long tire force} * \text{linear slip speed} * \text{slip ratio?}$

- Computation of the **energy consumption** and **achievable range** at different constant speeds, including consideration of the previous power loss contributions

- Execution of **tip-in and tip-off tests** to evaluate vehicle drivability² step-like acceleration (then deceleration after few seconds)

- Execution of **acceleration and braking tests** to compute the **level of recuperated energy** during the deceleration Neg. torque engine, but in regener. power at wheel is bigger than power at battery, beware of numerator/denominator in position of efficiency

- **Execution** of **emergency braking tests** in dry and wet tarmac conditions, with computation of the **resulting stopping distances**, and the potential consideration of the **electronic brake distribution (EBD)** and **anti-lock-braking system (ABS) interventions** (starting with wheel lock - no abs, wheel should remain locked and not spin backwards -> equations)

²[Direct yaw moment control actuated through electric drivetrains and friction brakes: Theoretical design and experimental assessment - ScienceDirect](#)

Longitudinal dynamics model and simulations

Concise project report

- Model layout (short description + manoeuvre parameters)
- Outputs (some figures + comments) "Wrong" results should be commented if not fixed
- Analysis of main results (e.g., regenerative braking capability, autonomy, etc...)
- Maximum length: 5 pages

Project full (working) model

- Initialization (Matlab script)
- Simulink model
- Results analysis (Matlab script)

Assessment details

- Submission deadline: 9 June 2024
- Discussion at the end of the module, before the exam session