TECHNOLOGIES FOR AUTONOMOUS VEHICLES

VEHICLE DYNAMICS

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Homework – Section 2

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,**
  angular wh. speed. w. tire relaxation
  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
  effect of Fz

- 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 ??)

- accel. pedal -> 20 ms -> motor "changes"
  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**

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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**

-> computation of wheel radius

- The tyres are **215/50R19**, 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 x 10^{-6} s^2/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

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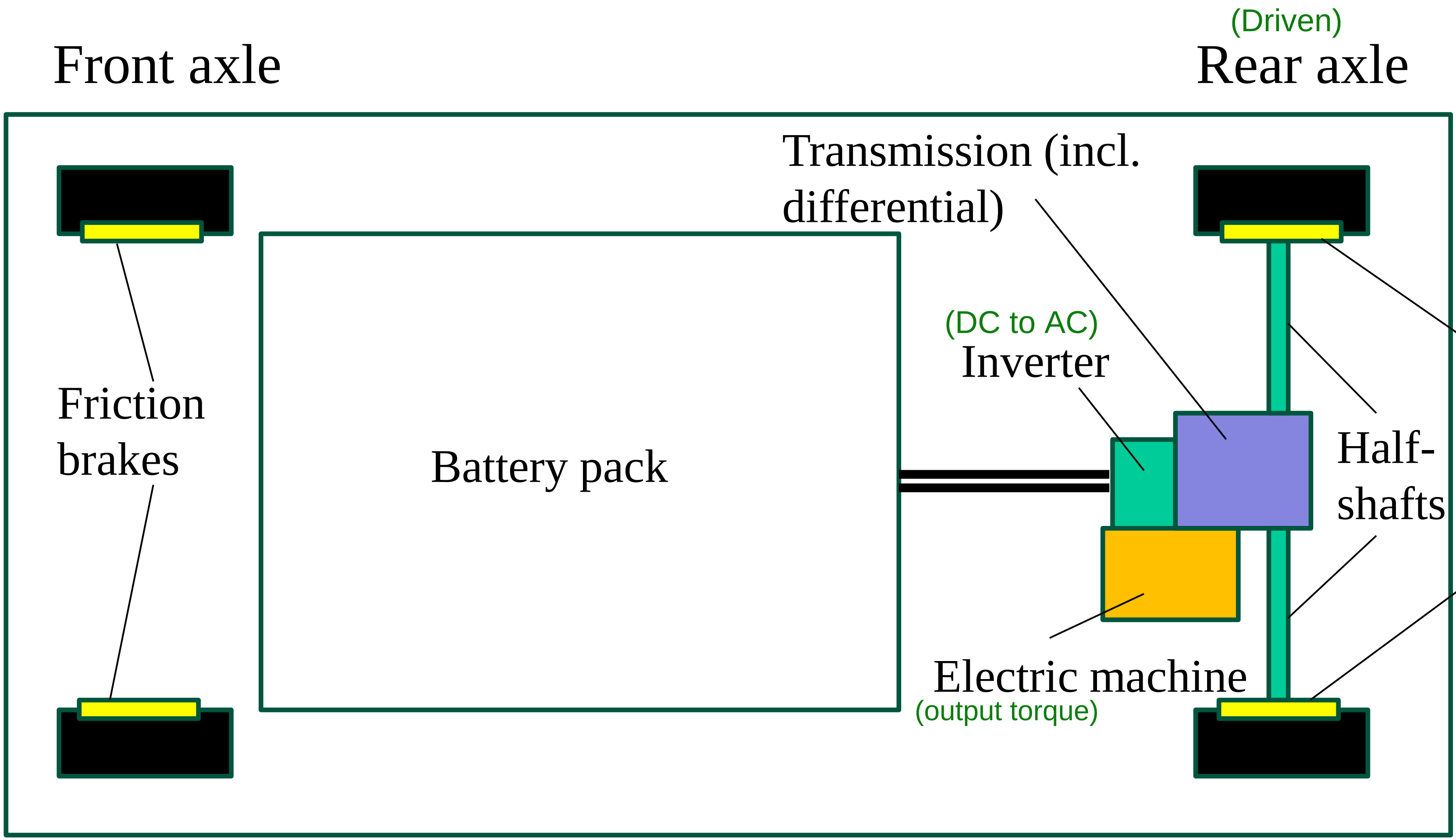
Case study vehicle

- 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 ms**[1] (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 m^2** and **0.27**
- All the other parameters and characteristics can be based on **reasonable assumptions** (and/or found online, etc)

[1]D. 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.

Homework – Section 2

Case study vehicle



ex. 100 Nm generated by electric machine -> 100*10.5*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

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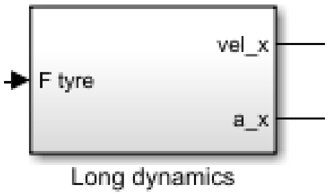
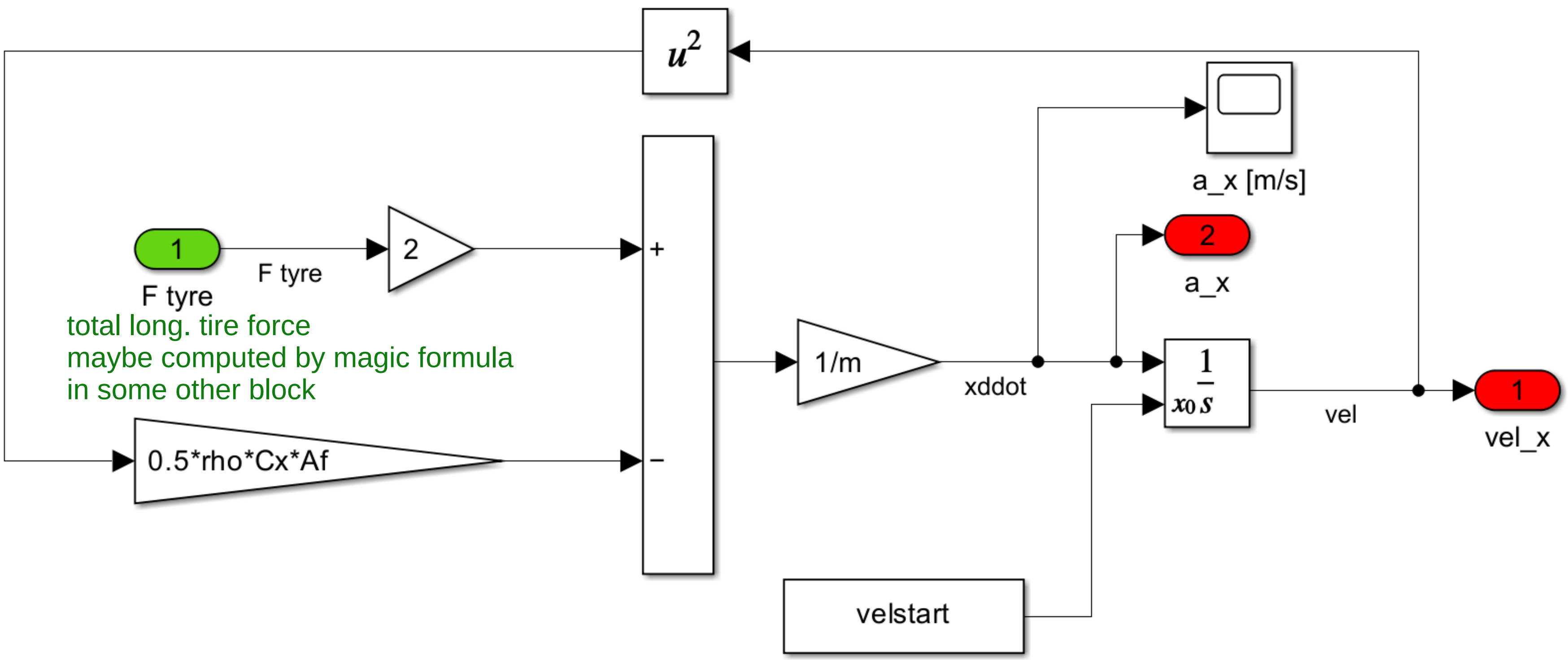
Expected outputs – the vehicle model



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



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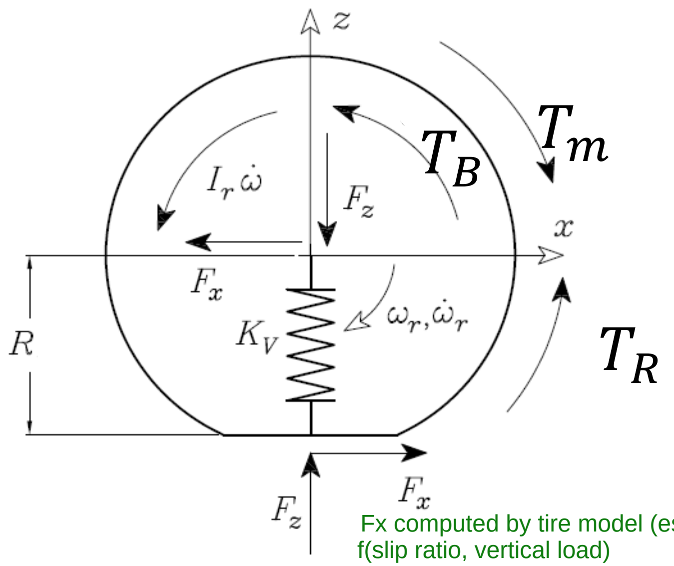
"total" model should contain long dynamics, many wheel dynamics, slip ratio, tire model

Either 4 wheels or simpler model with 1 wheel per axle

Expected outputs – the vehicle model



Fx computed by tire model (es. paceika 96)
f(slip ratio, vertical load)

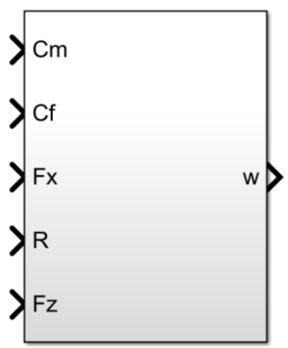
Rotational wheel dynamics

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

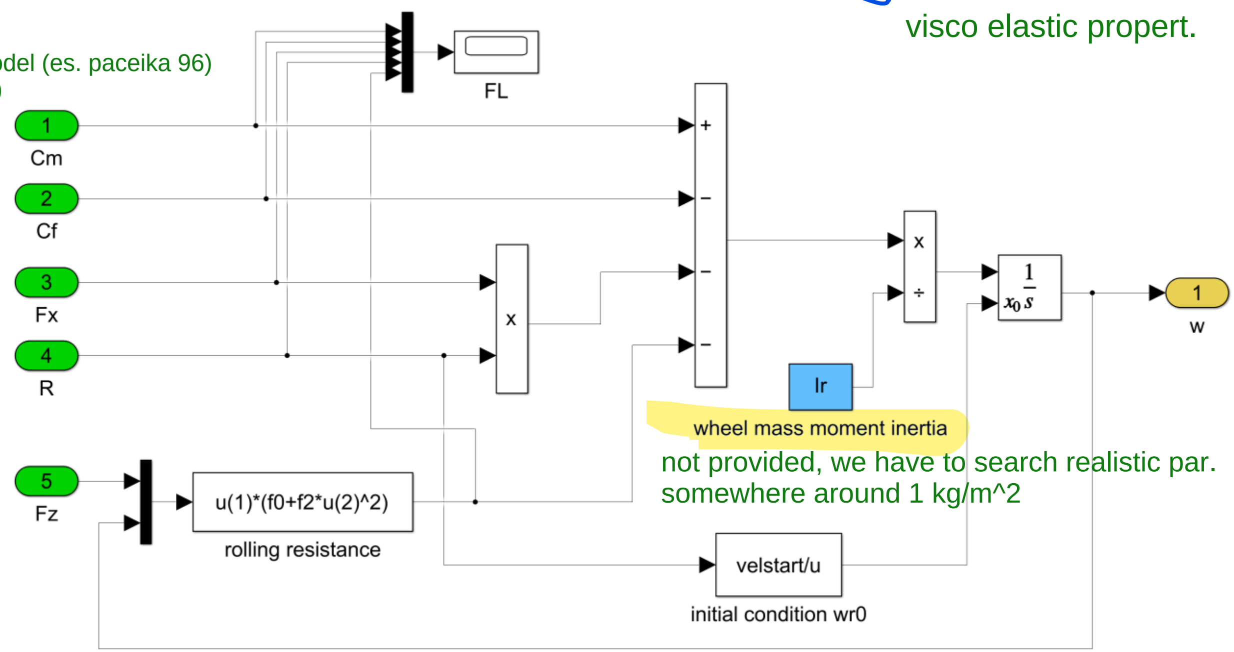
$$\dot{\omega}_r = \frac{T_m - T_B - T_R - F_x R}{I_r}$$

ang. accl. of each wheel

visco elastic propert.



wheel dynamics FL1



wheel mass moment inertia

not provided, we have to search realistic par.
somewhere around 1 kg/m^2

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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. resist. torque * wheel speed

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

long tire force * linear slip speed * 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 drivability[2] 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

Figure 5 + Paper 7 Figure 17 ?

Homework – Section 2

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

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