MASTER's DEGREE PROGRAMME

Automotive Mechatronics and Management

Drive Train Control Systems

SUBMITTED AS AN INDIVIDUAL REMOTE WORK

By

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1 Methodology

1.1 Driveline Modeling

I constructed a Simulink model that represents crucial components of the BEV's driveline. This included the electric motor, transmission, side shafts, and a simplified representation of the vehicle itself, referred to as the 'reduced vehicle model'. I used provided parameters such as stiffness, damping, and inertia to describe the physical characteristics of these components.

1.2 Resistance Modeling

I computed and modeled the total driving resistance (T_load) that the vehicle experiences, which are rolling, air resistance, and acceleration resistance by taking into account factors such as vehicle speed, vehicle mass, drag coefficient, reference area, air density, and rolling resistance coefficient.

1.3 Control System Design

I work with a PID control system. This controller uses the speed error (the difference between the desired and actual vehicle speed) as its input and generates a torque command for the electric motor.

1.4 WLTP Cycle Tracking

I imported the desired vehicle speed from the WLTP cycle and converted this speed into a desired motor speed. This was used as the reference signal for the PID controller. I tuned and adjusted the control system so that the actual vehicle speed closely follows this reference signal.

In the following pages, the calculation and model will be explained and presented.

2 Calculations & Model with Explanations

2.1 3DOF Driveline Model & Driving Resistance Calculations

- A fundamental part of the project was to build a 3DOF driveline model. The model encapsulates the interactions of the electric motor, transmission, and a simplified vehicle model.
- Total driving resistance acting on the vehicle is calculated based on various parameters of driving resistance.

2.2 Motor Torque and Speed (1D Look Up)

- The 1D lookup table can store data about the relationship between motor speed (ω) and torque (T_mot). Given a certain motor speed, the lookup table provide the corresponding torque.

2.3 Motor Torque Limiting (Saturation Dynamics)

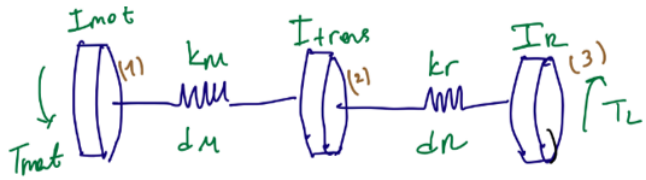
- The Saturation block is used to limit the torque output of the motor. This represents the physical limitations of the motor, where beyond a certain point, increasing the input current will not result in an increase in torque.
- Braking Torque Limiting: Similarly, when braking, the saturation function can be used to ensure that the braking torque doesn't exceed a certain safe limit.

2.4 PID Control

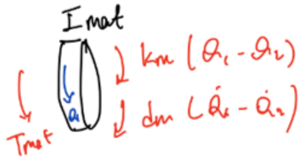
- PID was used to control the motor torque to drive the vehicle at desired speeds per the WLTP cycle.
- The proportional part of the controller responded to present speed errors, the integral part corrected for accumulated past errors, and the derivative part anticipated and mitigated potential future errors.

Detailed calculation steps and models will be presented in the following pages.

2.5 Calculations of BEV Driveline Model 3 DOF



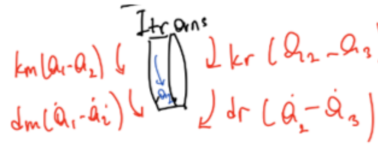
(1)



$$= T_{mot} - I_{mot} \cdot \ddot{\theta}_1 - k_m(\theta_1 - \theta_2) - d_m(\dot{\theta}_1 - \dot{\theta}_2) = 0$$

$$= \theta_1 = \frac{1}{I_{mot}}\left(T_{mot} - k_m(\theta_1 - \theta_2) - d_M(\dot{\theta}_1 - \dot{\theta}_2)\right)$$

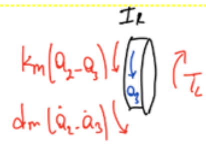
(2)



$$= k_m(\theta_1 - \theta_2) + d_m(\dot{\theta}_1 - \dot{\theta}_2) - \ddot{\theta}_2 \cdot I_{trans} - k_r(\theta_2 - \theta_3) - d_r(\theta_2 - \theta_3) = 0$$

$$= \ddot{\theta}_2 = \frac{k_m(\theta_1 - \theta_2) + d_m(\dot{\theta}_1 - \theta_2) - k_r(\theta_2 - \theta_3) - d_r(\theta_2 - \theta_3)}{I_{trans}}$$

(3)



$$= k_m(\theta_2 - \theta_3) + d_m(\dot{\theta}_2 - \dot{\theta}_3) - \ddot{\theta}_3 \cdot I_R - T_L$$

$$\theta_3 = \frac{\left(k_m(\theta_2 - \theta_3 + d_m(\dot{\theta}_2 - \dot{\theta}_3)\right) - T_L)}{I_R}$$

2.6 Driving Resistance Forces (F_z)

Driving Resistenence Equations

$F\_R = fr \cdot m \cdot g \cdot \cos\alpha$

$F\_L = c_w \cdot A \cdot \frac{rho}{2} \cdot v^2$

$F\_a = m \cdot \lambda \cdot \ddot{x}$

$F_{st} = mg \cdot \sin\alpha$

$$F_z = mg\left(fr \cdot \overset{1}{\cancel{\cos\alpha}} + \overset{0}{\cancel{\sin\alpha}}\right) + \frac{1}{2} c_w \cdot A \cdot rho \cdot v^2 + m \cdot \lambda \cdot \ddot{x}$$

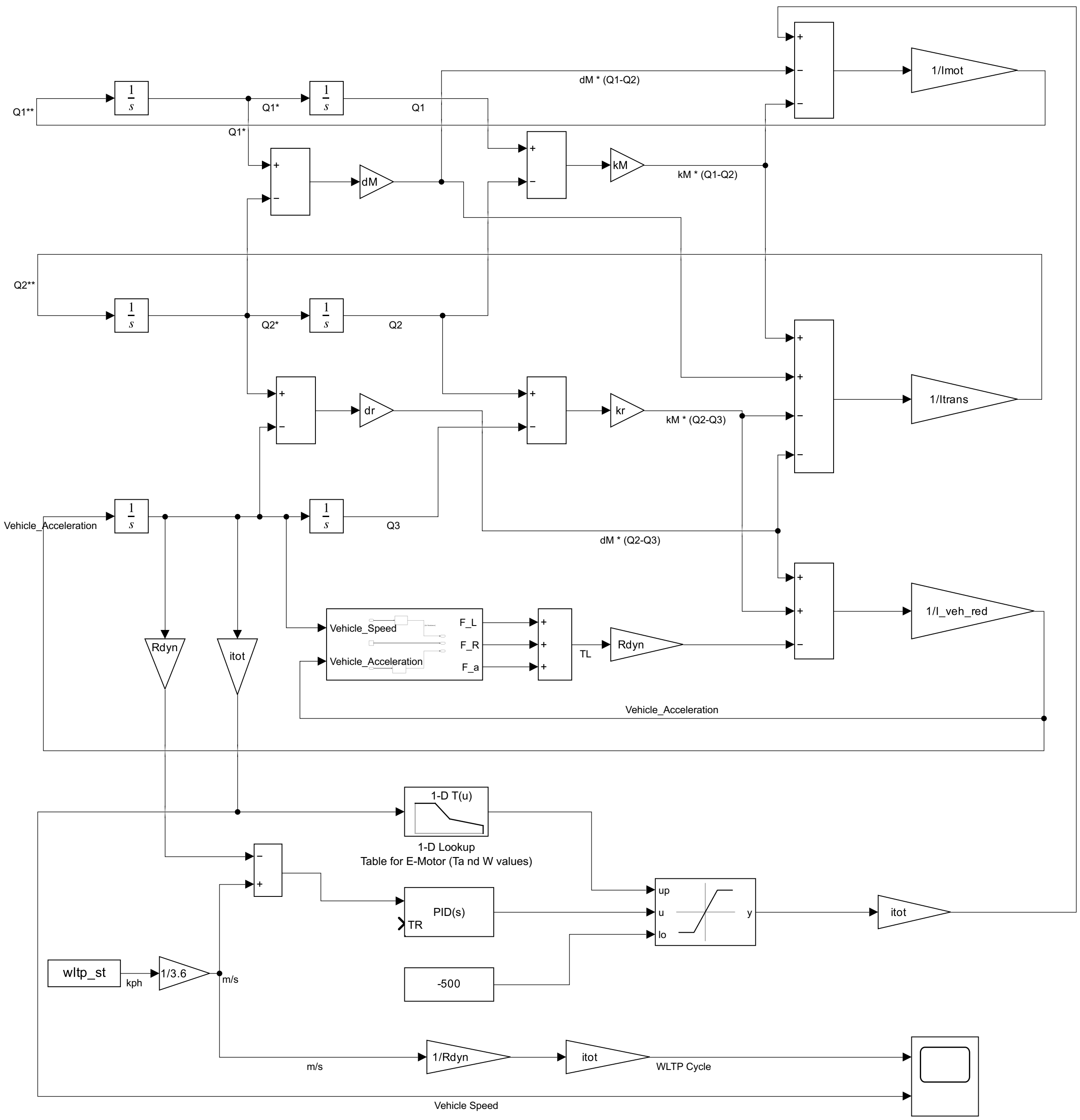
(1) $F_z = V_{mass} \cdot g \cdot fr + \frac{1}{2} c_w \cdot A \cdot rho \cdot v^2 + V_{mass} \cdot \lambda \cdot \ddot{x}$

(2) $\lambda = 1 + m_r / m$,

(3) $m_r = \frac{I_{red}}{R^2_{dyn}} = \frac{I_{mot} + I_{trans} \cdot \dot{i}^2_{tot}}{R^2_{dyn}}$

```
% Driveline Parameters
d = struct('T1', 400, 'W1', 300, 'T2', 200, 'W2', 500, 'T3', 100, 'W3', 1000); % Nm,↙
rad/s

% Vehicle and Transmission Parameters
vmass = 1370; % kg
Rdyn = 0.3; % m
itot = 10.2;
Imot = 0.9 ;  %kg*m^2
Itrans = 1.2; %kg*m^2
mr = ((Imot+Itrans)*(itot^2))/(Rdyn^2);
lamba = 1+(mr/vmass);

% Stiffness and Damping Parameters
kM = 13000; % Nms/rad
dM = 6.5;  % Nms/rad
kr = 201.5;
dr = 206;

% Air and Rolling Resistance Parameters
fr = 0.019;
cw = 0.31;
A = 2.15; % m^2
Rho = 1.2; % kg/m^3
g = 9.81;
F_L = cw*A*(Rho/2); % Air resistance
F_R = fr*vmass*g; % Rolling resistance

% Simplified Vehicle Inertia
I_veh_red = vmass * Rdyn^2 / itot^2;

% WLTP Data
filename = 'WLTP.xlsx'; % File name for WLTP
data = readmatrix(filename); % Read the matrix from the file
wltp_st = [data(:,1), data(:,2)]; % Time-WLTP combination
```

BEV_Model_DTCS_Project_Oral



C:\Users\cogo\Desktop\DTCS_Work\BEV_Model_DTCS_Project_Oral.slx

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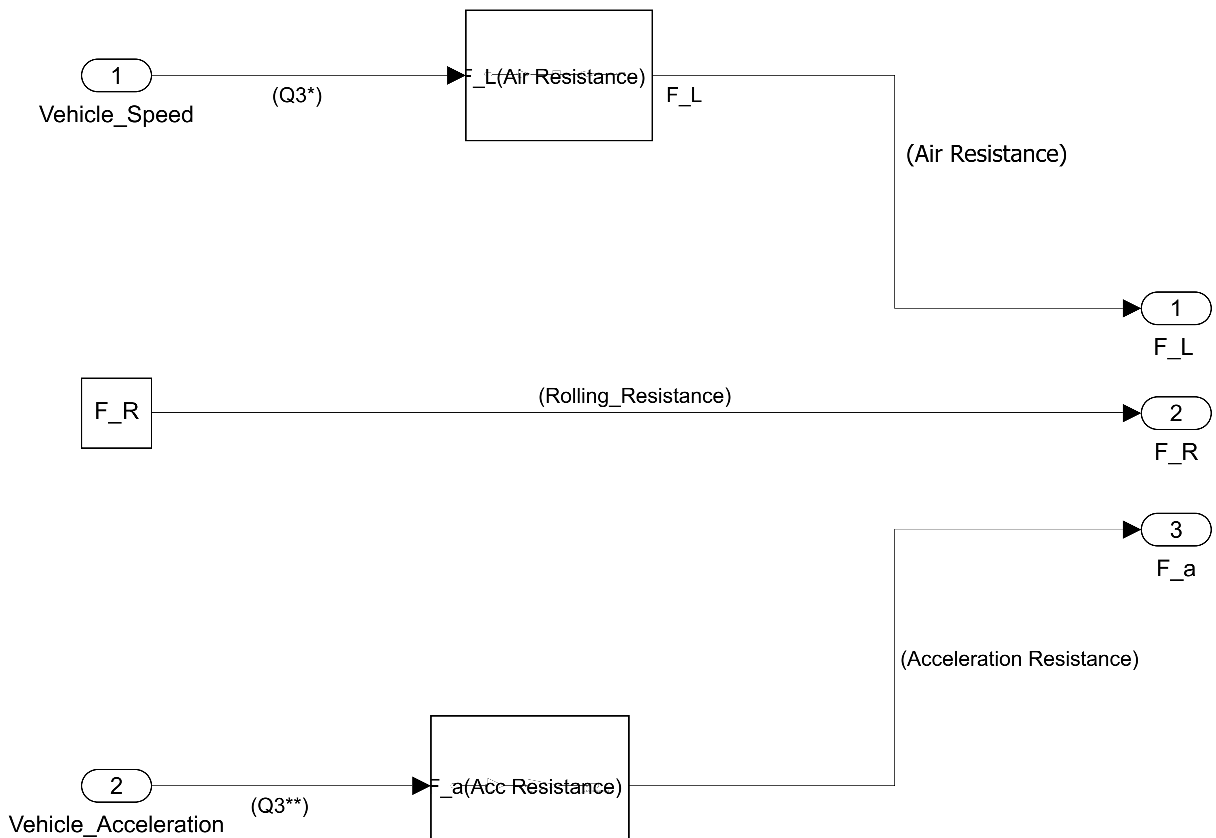
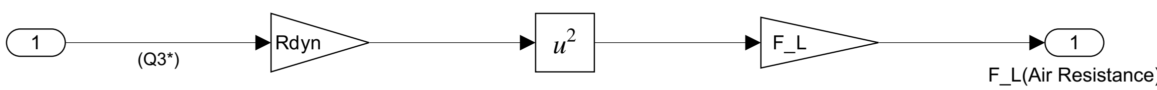
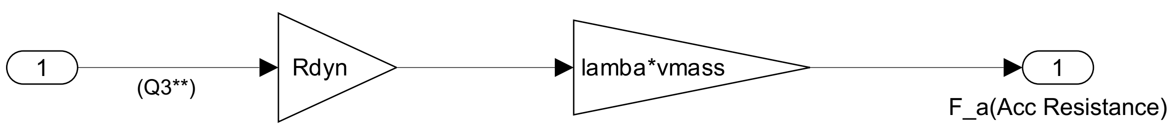
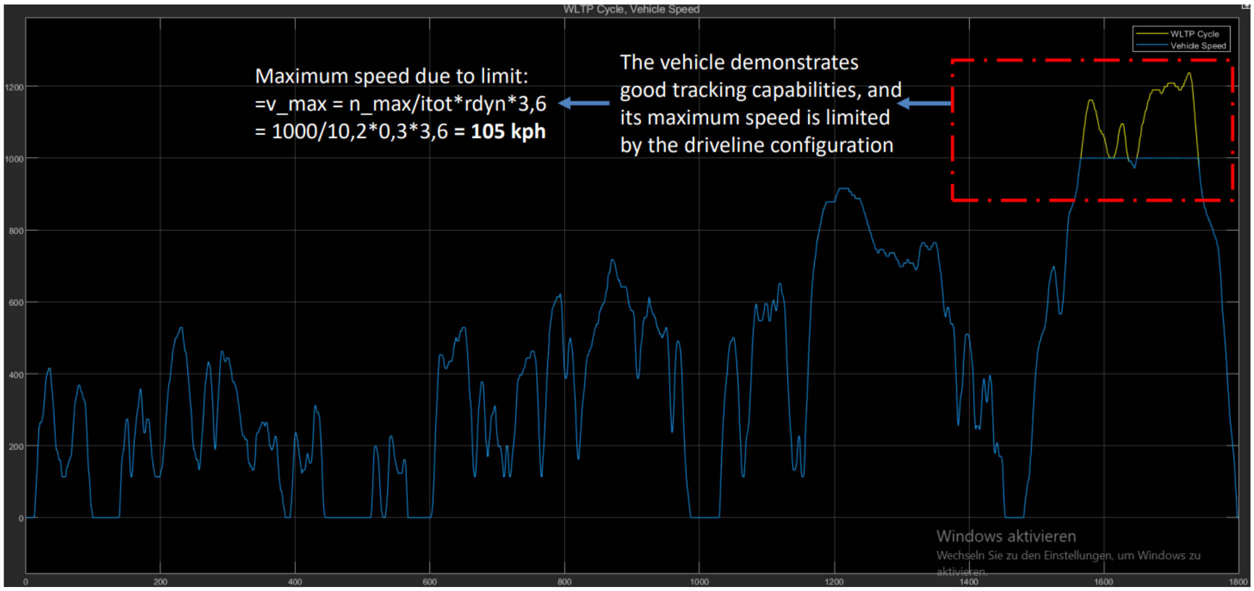

1
Vehicle_Speed
(Q3*)
F_L(Air Resistance)
F_L
(Air Resistance)
1
F_L
F_R
(Rolling_Resistance)
2
F_R
3
F_a
(Acceleration Resistance)
2
Vehicle_Acceleration
(Q3**)
F_a(Acc Resistance)


1
(Q3*)
Rdyn
u^2
F_L
1
F_L(Air Resistance)


1
(Q3**)
Rdyn
lamba*vmass
1
F_a(Acc Resistance)

3 Results and Interpretation

3.1 Discussion about the max speed of the vehicle on flat



The maximum speed of the vehicle on a flat road is determined by the parameters of the driveline model, notably the electric motor's maximum rotational speed, the gear ratio, and the dynamic wheel radius, and calculated as 105 kph. Given these constraints, the vehicle cannot exceed a specific speed limit, which is primarily due to the limitations of the electric motor and driveline setup.

3.2 Conclusion

Results, obtained from the three degrees of freedom (3DOF) driveline model and the designed PID controller, showed the effective tracking of the WLTP cycle. The model accurately represents the BEV's dynamic behavior, and the controller efficiently managed the torque of the electric motor based on the speed error.