Fuel consumption simulation

Vehicle dynamics

DEPARTMENT OF AUTOMOTIVE TECHNOLOGIES

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2014

Fuel consumption simulation

Analytic estimation in a steady state operation point

Steady state motion equation:

$$\left.\begin{aligned} F_{tr} &= m_v g(sin\alpha + f cos\alpha) + \frac{1}{2} c_w A_v \rho_a v_v^2 \\ F_{tr} &= \eta \frac{M_e i_{gb} i_{fg}}{r_w} \end{aligned}\right\} \Longrightarrow M_m = \frac{r_w \left[m_v g(sin\alpha + f cos\alpha) + \frac{1}{2} \rho_a c_w A_v v_v^2\right]}{\eta i_{gb} i_{fg}}$$

Actual engine speed:

$$\omega_e = v_v \frac{i_{gb} i_{fg}}{r_w}$$

Actual engine power:

$$P_e = \omega_e M_e$$

Fuel consumption simulation

Analytic estimation in a steady state operation point

The actual fuel mass flow rate (based on the brake specific fuel consumption characteristics):

$$\dot{m}_f = b_{spec} P_e \left[\frac{kg}{s}\right]$$

Attention: the unit of the BSFC is usually $\left[\frac{g}{kWh}\right]$!

The actual fuel mass flow rate (based on the effective efficiency of the engine):

$$\dot{m}_f = \frac{P_e}{\eta_{e,eff} H_f}$$

The BSFC and the effective efficiency can be determined from each other.

The fuel consumption on 100km:

$$V_t = 10^8 \frac{\dot{m}_f}{v_v \rho_f} \text{ [l/100 km]}$$

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Analytic estimation in a steady state operation point

How much is the actual fuel consumption (related to 100km) of the vehicle that has 15 tons, it runs up on a 5% angle slope with 70km/h. The speed is constant, the engine's actual effective efficiency is 35%.

Given data: the fuel heat capacity 44.8 MJ/kg, fuel density 830 kg/m^3, vehicle's front area and drag coefficient: 5 m^2 and 0.4, rolling resistance: 0.015, air density: 1.2 kg/m^3.

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Analytic estimation in a steady state operation point

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$$\alpha = arctg(0.05) = 2.86°$$

$$F_{tr} = mg(sin\alpha + f cos\alpha) + \frac{1}{2} c_w A \rho v^2$$

$$= 10000 \cdot 9.81 \cdot (sin2.86° + 0.015 \cdot cos2.86°) + \frac{1}{2} \cdot 0.4 \cdot 5 \cdot 1.2 \cdot \left(\frac{70}{3.6}\right)^2 = 6818N$$

$$P_{tr} = F_{tr} v = 6818 \cdot \frac{70}{3.6} = 132575W$$

$$V_f = \frac{10^8 P_e}{\eta_{m,eff} H_f v \rho_f} = \frac{10^8 \cdot 132575}{0.35 \cdot 44.8 \cdot 10^6 \cdot \frac{70}{3.6} \cdot 830} = 52.4\ l/100km$$

Fuel consumption simulation

Dynamic fuel consumption simulation

Presumptions:

- The vehicle speed is higher than the minimum stable speed,
- The vehicle runs on flat ground,
- The time of gear changing in negligible.

Boundary conditions:

- The input (reference signal) vehicle speed profile in function of the time

Simplified driver model:

- Throttle control input ($0 \le u_{throttle} \le 1$)
- Brake control input ($0 \le u_{brake} \le 1$)
- Gear selection control

Fuel consumption simulation

Fuel consumption simulation – vehicle motion equations

$$\delta m_v \ddot{s}_v = F_{tr} - F_{brake} - m_v g f - \frac{1}{2}\rho_a c_w A_v v_v^2$$

$$F_{tr} = \frac{M_e i_{gb} i_{fg} \eta}{r_w}$$

$$\omega_e = \frac{v_v i_{gb} i_{fg}}{r_w}$$

$M_e = u_{throttle} M_{e,max}(\omega_e)$ - maximum torque charasteristic is given

$F_b = u_{brake} F_{brake,max}$ - maximum brake force is also given

$v_v \leq v_{limit}$ - speed limit

$\dot{m}_f = b_{spec} P_e$ - BSFC characteristic is given

$$V_f = \frac{\dot{m}_f}{\rho_f v_v}$$

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Fuel consumption simulation – driver modelling

Actual gear selection: the selected gear should provide the the smallest difference from the pre-given target engine speed:

$$i_{gb,aim} = \frac{\omega_{e,aim} r_w}{v_v i_{fg}} \Longrightarrow i_{gb} = i_{gb,i}\Big|_{|i_{gb,aim} - i_{gb,i}| = min!,\ i=1,2,\dots,n}$$

The state change of the throttle control is proportional with difference between the actual and the target vehicle speed (with a tolerance interval):

$$\frac{du_{throttle}}{dt} = \begin{cases} -P_{throttle}(v_v - v_{ref} + v_{tol}), if\ v_v - v_{ref} < -v_{tol} \\ 0, \text{ if } |v_v - v_{ref}| < v_{tol} \\ -P_{throttle}(v_v - v_{ref} - v_{tol}), if\ v_v - v_{ref} > v_{tol} \end{cases}, but\ 0 \le u_{throttle} \le 1$$

The state change of the brake control is proportional with difference between the actual and the target vehicle speed (with a tolerance interval). There is no throttling and braking at the same time:

$$\frac{du_{brake}}{dt} = \begin{cases} P_{brake}(v_v - v_{ref} + v_{tol}), if\ v_v - v_{ref} < -v_{tol} \\ 0, \text{ if } |v_v - v_{ref}| < v_{tol} \\ P_{brake}(v_v - v_{ref} - v_{tol}), if\ v_v - v_{ref} > v_{tol} \end{cases}, but\ 0 \le u_{brake} \le 1\ and\ u_{brake} =$$

$0, if\ u_{throttle}$>0

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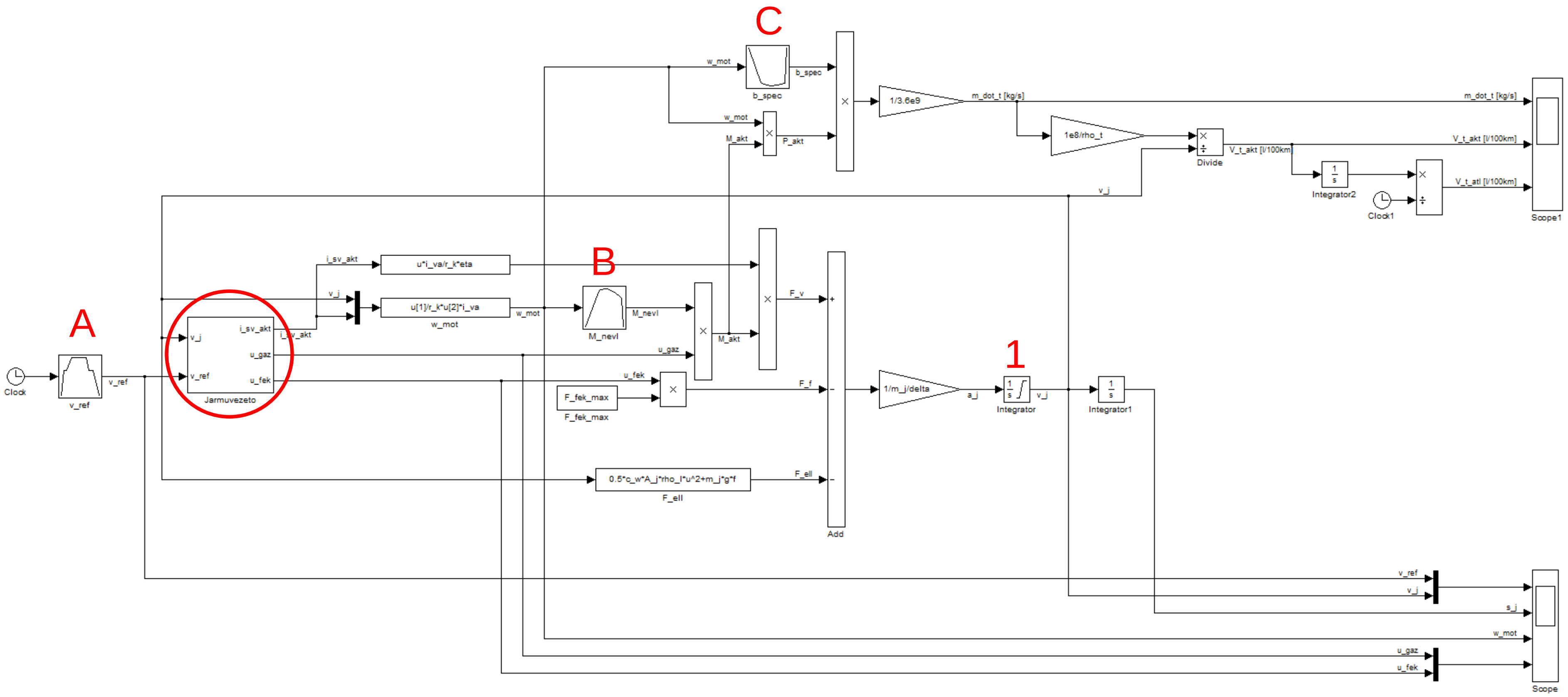
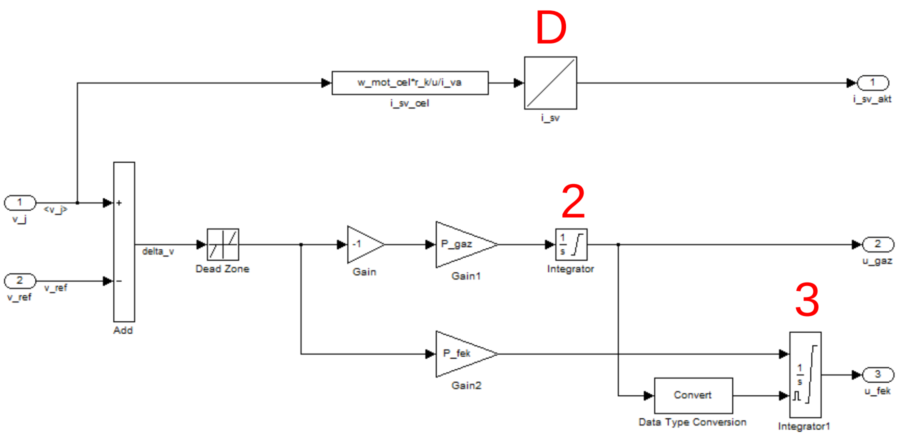
Dynamic fuel consumption simulation



Fuel consumption simulation

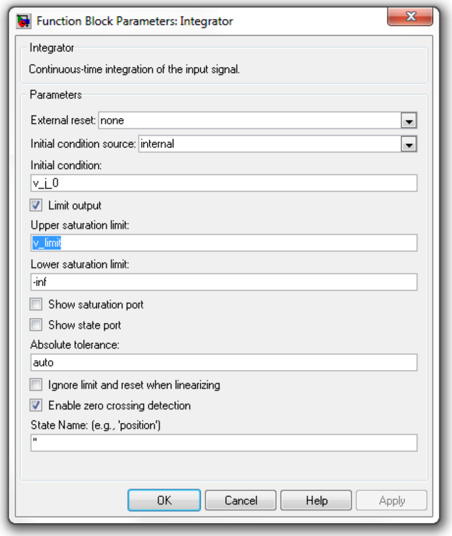
Dynamic fuel consumption simulation



Fuel consumption simulation

Dynamic fuel consumption simulation

1



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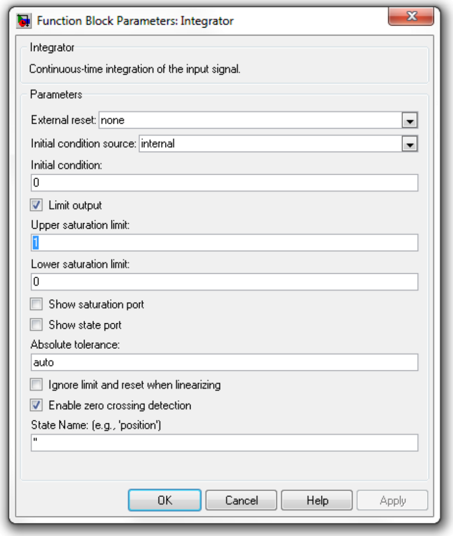

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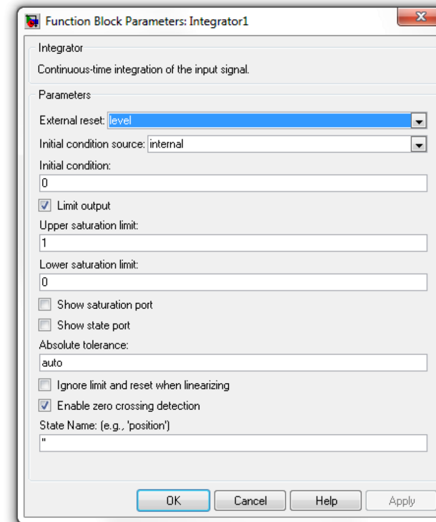

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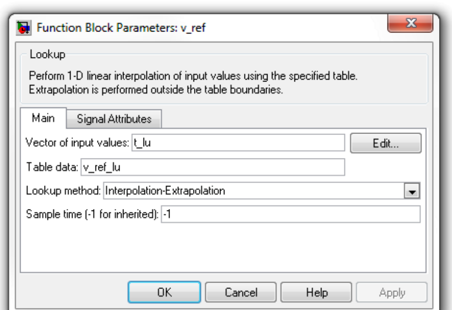

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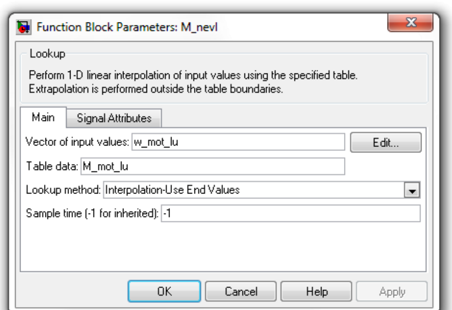

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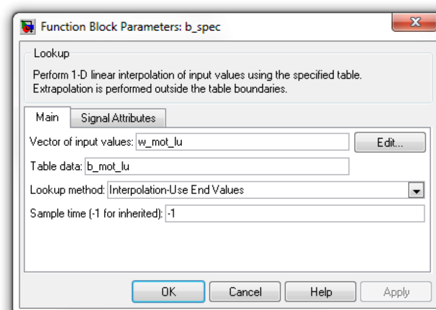

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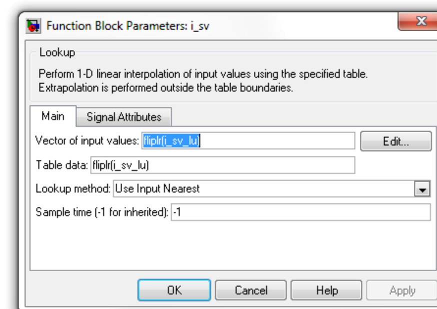

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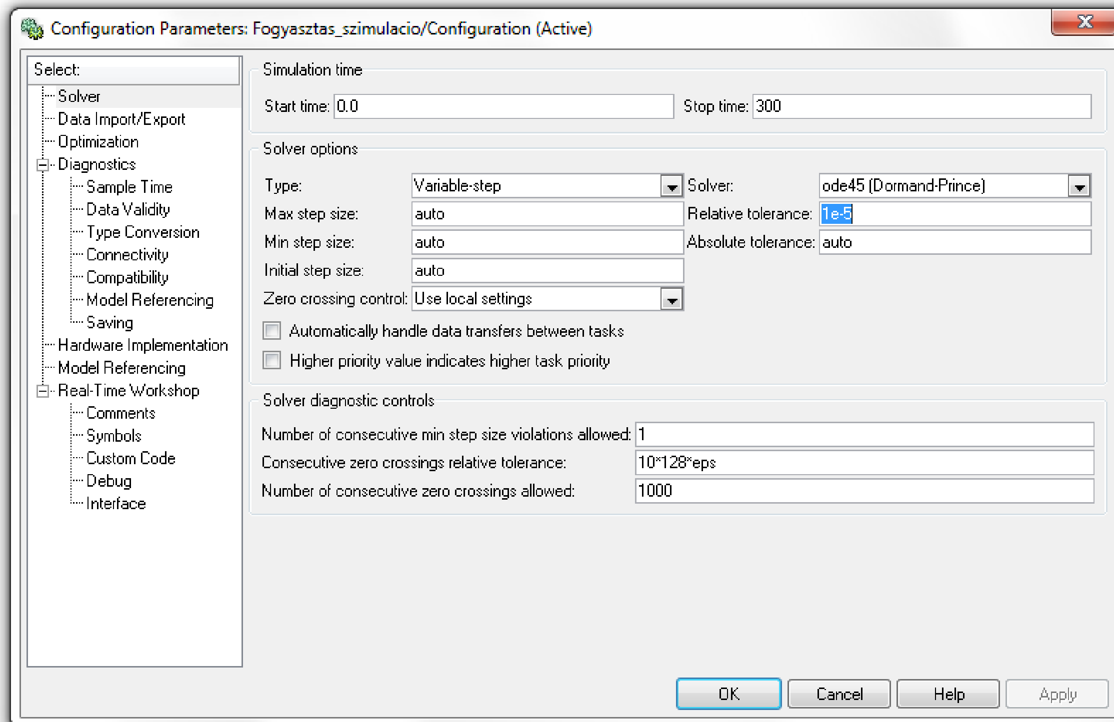
Dynamic fuel consumption simulation

```
m_j=15000; % [kg] vehicle mass
delta=1.1; % [-] rolling mass factor
A_j=5; % [m^2] front area
c_w=0.5; % [-] drag coefficient

i_va=3.5; % [-] final gear ratio
r_k=0.4; % [m] wheel rolling radius
eta=0.95; % [-] mechanical efficiency of the powertrain

F_fek_max=100000; % [N] max brake force

f=0.015; % [-] rolling resistance factor
rho_l=1.293; % [kg/m^3] air density
g=9.81; % [m/s^2] gravitational acceleration
rho_t=830; % [kg/m^3] fuel density

w_mot_cel=1500*2*pi/60; % [rad/s] target engine speed
v_limit=90/3.6; % [m/s] speed limit
v_tol=1/3.6; % [m/s] speed tolerance interval

% Engine characteristics
w_mot_lu=[0 800 1000 1500 2000 2500 2600]*2*pi/60; % [rad/s]
M_mot_lu=[0 560  650  660  600  500    0]; % [Nm]
b_mot_lu=[500 230  215  200  210  220  500]; % [g/kWh]

% Gear ratios
i_sv_lu=[6.3 3.5 2.1 1.4 1 0.8]; % [-]

% Driver model
P_gaz=0.2; % [1/m] throttle controller proportional part
P_fek=0.05; % [1/m] brake controller proportional part

% Reference speed profile
t_lu=    [ 0 20 40 80 200 220 250 300]; % [s]
v_ref_lu=[10 50 50 70  70  50  50  10]/3.6; % [m/s]

%Initial conditions
v_j_0=1000*2*pi/60*r_k/i_va/i_sv_lu(1); % [rad/s] initial vehicle speed
```



Thank you for your attention!

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