Mass estimation functions

On-board Mass Estimation functions in the transmission management system

The total vehicle mass is one of the most important estimated physical quantities in the vehicle. It is estimated using different methods based on the sensors and signals available in any particular vehicle. This presentation describes some mass estimation methods and algorithms implemented in the vehicles ECU.

The mass estimation function uses information from different estimation methods to create a merged vehicle mass estimate.

The information is generated in order to determine the correct gearshift strategy.

Gearshift based vehicle mass estimation

This method estimates the vehicle mass by comparing traction force and vehicle acceleration before, during and after a gearshift.

The method is based on Newton’s second law

\[ F_t - F_r = ma \]

Where \( F_t \) is the traction force, \( F_r \) is the driving resistance, \( m \) is the vehicle mass and \( a \) is the vehicle acceleration.

It is assumed that all longitudinal forces acting on the vehicle, except for the traction force generated by the driveline, are roughly constant during short time periods. The force assumed to be constant is the driving resistance, created by rolling resistance, air resistance and the road inclination.

The traction force is calculated from the engine torque, using gear ratios and the wheel radius, according to the following formula:

\[ F_t = \frac{T_{\text{engine}} \cdot r_{\text{driveline}}}{r_{\text{wheel}}} \]

Where \( F_t \) is the traction force, \( T_{\text{engine}} \) is the engine torque, \( r_{\text{driveline}} \) is the total gear ratio of the driveline, and \( r_{\text{wheel}} \) is the wheel radius. The acceleration is calculated based on wheel sensor data.

The following set of equations is formed

\[
\begin{align*}
(F_1 + F_c) &= ma_1 \\
(F_2 + F_c) &= ma_2
\end{align*}
\]
Where \( m \) represents the vehicle mass, \( F_1 \) and \( F_2 \) represents a traction force data pair, \( a_1 \) and \( a_2 \) represents an acceleration data pair, and \( F_c \) represents the forces that are assumed to be constant. The vehicle mass is obtained by solving for \( m \):

\[
 m = \frac{(F_1 + F_c) - (F_2 + F_c)}{a_1 - a_2} = \frac{F_1 - F_2}{a_1 - a_2}
\]

Two traction force and vehicle acceleration data pairs are needed for each mass estimate, and a complete gearshift can result in up to three separate mass estimation events based on the data before and during the gear shift, during and after the gear shift and finally before and after the gear shift.

**Mass estimation with help of an accelerometer**

This method estimates the mass of the vehicle using an accelerometer. The signal from the accelerometer can be described by the following formula:

\[
 a_{sensor} = a + g \sin \alpha
\]

Where \( a \) is the acceleration of the vehicle, \( g \) is 9.81 m/s\(^2\) and \( \alpha \) is the road grade. Newton's second law is used to formulate the following set of equations:

\[
 m \dot{m} = 0 + w_{noise}
\]

\[
y = F_{traction} - F_{drivingResistance} = a_{sensor}m + n_{noise}
\]

The traction force is calculated from the engine torque. The driving resistance is estimated.

A Kalman filter with one state is used to estimate the vehicle mass. Written in discrete state space form, with \( x = m \), the equations becomes:

\[
 A = 0
\]

\[
 C = a_{sensor}
\]

\[
y = F_{traction} - F_{drivingResistance}
\]

The estimated mass is calculated as follows:

\[
 \hat{x}_{t|t} = \hat{x}_{t|t-1} + K(y_t - C\hat{x}_{t|t-1})
\]

A suitable driving case has to be identified for the model to be valid.

**Mass estimation during acceleration**

This method calculates the vehicle mass during a change in vehicle acceleration, without gearshifts. It is based on the formula:

\[
 F_t = ma + F_r
\]
where

\[ F_t \] is the traction force, obtained from the measured engine torque, \( m \) is the vehicle mass, \( a \) is the acceleration of the vehicle obtained from wheel sensors, and \( F_r \) is the current driving resistance. The driving resistance depends on the slope of the road, air resistance and the rolling resistance.

The expression is differentiated with respect to time, assuming the mass is constant:

\[
dF_t = m \cdot da + dF_r
\]

The driving resistance is assumed to be constant for a short time. This yields the following formula:

\[
dF_t = m \cdot da
\]

Continuous measurements of the vehicle's traction force and the acceleration are obtained and differentiated, to solve for the vehicle mass.

A suitable driving case has to be identified for the model to be valid.

**Selection among the calculated mass estimates**

In order to obtain a stable and accurate final mass estimation as possible, the outputs of the individual mass estimation algorithms are processed statistically. The final estimation represents the Gross Train Weight (GTW) or Gross Vehicle Weight (GVW).

The system can classify the quality of the weight estimation and deliver it with the weight indicated. A deviation of 1 to 2 tons or 5% of the total mass is a fairly good estimation.