Japan Simulation Model Overview

Simulation methods for Fuel Consumption measurement of HD and HD hybrid vehicles

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Fuel consumption for HDV is calculated using Simulation method.

Assumptions for the calculation:

- **FC value is vehicle based one.**
  Not enough to improve only engine performance. Combination of engine and transmission is important.

- Regulation Target is for vehicle manufactures.
  Vehicles without loading platform; Cab and chassis

- To calculate simply, small things are neglected.
  e.g. Rolling resistant coefficient is set to the constant value based on the vehicle weight.
Simulation Method Overview

Driving cycle = \{ Urban driving mode, Interurban driving mode \}

Conversion program
- Determine gear-shift positions.
- Calculate engine speed and torque.

Vehicle specifications and maximum engine torque

Engine Operating Mode

Fuel efficiency map

Engine speed (rpm)

Torque (Nm)

Fuel consumption

Fuel efficiency

*Before simulation, perform engine operation tests to create a fuel efficiency map

Computing

\[
\text{Fuel consumption} = \sum_{i=\text{start}}^{\text{end}} F.C.(i)
\]

Phase of conversion

Cycle based on vehicle speed

Cycle based on engine speed and engine torque

Phase of calculation of fuel efficiency

Heavy Duty Vehicle Efficiency: Aligning Standards Internationally, Integration of Engines and Powertrains Technical Workshop
Conversion Program Overview

Driving mode

Conversion program
Determine the shift lever position

Engine operating mode
• Engine speed
• Engine torque

The vehicle specifications
(technical data)
• Full load engine torque for each engine speed
• Idling engine speed
• Rated engine speed
• Maximum engine speed with load

Drivetrain related parameters
• Number of transmission gears
• Transmission gear ratios
• Final reduction gear ratio
• Tire dynamic load radius

Driving resistance parameters
• Rolling resistance coefficient
• Air resistance coefficient

Vehicle weight related parameters
• Vehicle curb weight
• Maximum load
• Riding capacity

Engine torque
Time (s)

Engine speed
Time (s)
Flow of Calculation Phase

\[ E = \frac{1}{\left( \alpha_u / E_u + \alpha_h / E_h \right)} \]

- **E**: Fuel efficiency of HD vehicle mode (km/L)
- **E_u**: Urban driving mode fuel efficiency (km/L)
- **E_h**: Interurban driving mode fuel efficiency (km/L)
- **\( \alpha_u \)**: Proportion of urban driving mode
- **\( \alpha_h \)**: Proportion of interurban driving mode
Correlation between Simulation and Actual Vehicle Tests

◆ Most important point in the simulation is whether the results correspond to the real world or not.

◆ When fuel efficiency standard was set up, validations for simulation and actual engine were conducted. But, more than half of engines used for validation were Natural Aspiration engines. (NA engine is not in existent today.)

◆ Comparison tests were conducted with actual vehicles on chassis dynamometer, driving of JE05 and inter-city mode.

◆ Matching assessment of engine with vehicle was also conducted.
## Test Vehicle Specification

<table>
<thead>
<tr>
<th>Vehicle ID</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Displacement L</td>
<td>9.84</td>
<td>12.88</td>
<td>13.07</td>
</tr>
<tr>
<td>Max.power kW/rpm</td>
<td>279/2000</td>
<td>257/2000</td>
<td>279/1800</td>
</tr>
<tr>
<td>Max.torque Nm/rpm</td>
<td>1800/1400</td>
<td>1810/1100</td>
<td>1648/1400</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Injection system</th>
<th>Common rail</th>
<th>Common rail</th>
<th>Unit injector</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aftertreatment device</td>
<td>DPF</td>
<td>Urea SCR</td>
<td>Urea SCR</td>
</tr>
<tr>
<td>Curb mass kg</td>
<td>11330</td>
<td>9630</td>
<td>10270</td>
</tr>
<tr>
<td>GVW kg</td>
<td>24940</td>
<td>23300</td>
<td>24980</td>
</tr>
<tr>
<td>Vehicle weight at test</td>
<td>18135</td>
<td>17625</td>
<td>16465</td>
</tr>
<tr>
<td>Transmission</td>
<td>7MT</td>
<td>7MT</td>
<td>7MT</td>
</tr>
<tr>
<td>Driving distance km</td>
<td>221000</td>
<td>25650</td>
<td>68290</td>
</tr>
<tr>
<td>Emission regulation</td>
<td>'05</td>
<td>'05</td>
<td>'05</td>
</tr>
</tbody>
</table>

3 test vehicles are in the same weight category but different manufactures. All of tests were conducted on chassis dynamometer.
CO₂ Emissions in Steady State Cycle

Engine operating of D13 mode is determined by engine speed and torque. CO₂ emissions in steady state cycle from 3 vehicles are almost same level ••• equivalent engine thermal efficiency.
FC Measurement Test Results

Equivalent engine thermal efficiency, but Vehicle A is inferior in fuel consumption. Engine reduces NOx only with EGR, but due to small displacement Vehicle A had to often use high loaded area, where the fuel consumption in EGR get worse.
Relationship between Vehicle Tests and Simulation

The difference is within 0.1 km/L.
Good correlation between actual vehicle test and simulation.
Fuel consumption inferior in Vehicle A was also observed.
Assumption in Using 12-speed AMT

Many vehicles meeting fuel efficiency standard have 12-speed AMT. With Vehicle B and Vehicle C, the effect of 12-speed AMT on FC was estimated by the simulation.

<table>
<thead>
<tr>
<th>Vehicle ID</th>
<th>Fuel consumption ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>0.97</td>
</tr>
<tr>
<td>C</td>
<td>0.98</td>
</tr>
</tbody>
</table>

- 2.7% improved
- 1.1% improved
Maximum Torque Curve in Each Engine

The effect of FC improvement devices vary with engine or vehicle characteristics
FC or emission test method for HD HEV

In vehicles of conventional engine, the engine speed or torque condition can be calculated by the vehicle specification and vehicle speed pattern.

But in hybrid vehicles, engines are sometimes assisted by electric motor(s), **power demand for the vehicle is not always corresponded to the actual engine output**.

In order to resolve this issue, HILS (Hardware in the Loop Simulator) method was adopted to emission and FC measurement for HD HEV.

Other than HILS method, system bench (power pack) method is also certificated.
* Exhaust emission and fuel consumption measurement procedure for Heavy Duty Hybrid Vehicle

Establish the measurement procedure for Heavy Duty Hybrid Vehicle using HILS method for the first time in the world in Japan

Start discussion of international regulation based on Japanese regulation

* Real time simulation using on-board hybrid ECU detached from heavy duty HEV

Vehicle base procedure

HILS (Hardware In the Loop Simulator)

Vehicle model

Driver Model

Battery Model

Inverter

Motor Model

E/G Model

Vehicle parameter inputs:
- M/G efficiency map
- FC map
- Vehicle spec. etc.

JE05 real time simulation driving

Obtaining E/G rpm, E/G Torque operation signal

Obtaining Engine operating region

Operating the Engine

Measurement of Exhaust Emission

Engine speed

Exhaust Emission Measurement

Calculate Fuel Consumption

Emission and Fuel Consumption Measurement

Execute emission test using engine speed and torque signal with the engine dismantled from vehicle only
HILS System for FC Simulation

Driver model
- Acceleration & Braking

HEV model
- Engine
- MG
- Inverter
- Capacitor/Battery

Main parameters
- Engine (Torque map)
- MG (Torque map, Electric power consumption map)
- RESS (Internal resistance, Open-circuit voltage)
- Vehicle mass
- Inertia
- Transmission efficiency
- Gear ratio

Digital signal processor

Actual ECUs

Simulation results
- Calculated fuel economy with F.C. map
- Measure exhaust emissions with an engine unit

Reference vehicle speed
(JE05 driving cycle)

Vehicle Speed (km/h)

Time (sec)

24V Power Supply

Heavy Duty Vehicle Efficiency: Aligning Standards Internationally, Integration of Engines and Powertrains Technical Workshop
Adding regen. brake calculation for conversion program for conv. HD vehicle.

**Vehicle Speed**

- JE05 Driving Cycles

**Input Items**

1. Same Items with Conventional Vehicles
   - Vehicle Mass
   - Road Load
   - Engine Speed
   - Engine Torque
   - Gear Ratio
   - Gear Efficiency

2. Special Items
   - Max. Regeneration Torque or Ratio of Regenerative Brake/ Mechanical Brake

**HEV Conversion Algorithm**

- **Vehicle Basis**
  - Engine
  - MG: Motor/Generator
  - TM: Transmission

- **Hybrid System Basis**
  - Engine
  - Inverter
  - MG
  - RESS
  - Engine Dynamometer (ED)
  - Exhaust Emission Measuring
HILS Method for Fuel Consumption

**<Vehicle Basis>**

JE05 Driving Cycles

![Vehicle Speed vs. Time](chart1)

Acceleration & Braking

*Real HEV*

**<Conversion with HILS>**

Calculating Engine speed, torque and FC at small ΔSOC condition.

**<Engine Basis>**

Engine Speed vs. Time

Engine Load vs. Time

Fuel Consumption vs. Time

*HEV Model HIL Simulator*

**<Engine Basis>**

Engine ECU - Inverter - Energy Storage System (ESS) - Hybrid ECU - Driver Model - Acceleration & Braking - JE05 Driving Cycles
Fuel Consumption of Commercial HD HEV

HEV is not suitable for a long haul trucks, but for small sized trucks or route buses.

Example of route bus:

Bus with conventional diesel engine

Approved FC value

1st generation HEV had low regeneration efficiency and same FC level as existing vehicles. The latest HEV was improved.

HEV bus

1st generation in ‘06

2nd generation in ‘11

Approved FC value

4.25km/L

4.60km/L

4.25km/L
FC of HD HEV in Real World

FC comparison between diesel bus and hybrid bus by a route bus company in Tokyo (yearly average)

<table>
<thead>
<tr>
<th>Type</th>
<th>Fuel consumption km/L</th>
<th># of the vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Certification value</td>
<td>Real world</td>
</tr>
<tr>
<td>Conventional</td>
<td>4.25</td>
<td>2.18</td>
</tr>
<tr>
<td>HEV 1st gen.</td>
<td>4.25</td>
<td>2.25</td>
</tr>
<tr>
<td>HEV 2nd gen.</td>
<td>4.60</td>
<td>2.55</td>
</tr>
</tbody>
</table>

FC in real world is significantly worse than approved value. 2 reasons: Average vehicle speed is lower than JE05, and air conditioner is used in summer.

In real world, 1st generation HEV had the same level of FC as existing vehicles, but in 2nd generation FC was improved up to near approved value’s difference.

FC measurement with HILS method has good correlation with FC in real world. HILS is appropriate for FC evaluation.
WHTC defines motoring torque of ICE as braking side.

=> Motoring torque shall be replaced by appropriate recuperating power calculated on WHVC on flat condition with some vehicle data, i.e. tire, diff, TM and air/rolling resistance, etc. Detailed replacing method is now under discussing.

WHTC normalized speed / torque source: GRPE/WHDC/FE31('09.6)
Series hybrid shall be applied with WHTC normalized "motor" speed/torque method as well.

=> Japan is afraid of the deviation from the actual vehicle behavior

Full load curve of traction electric motor

Without TM
8.6km/h / 1000rpm
The last message

Thank you for your kind attention

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