Vehicle Simulation for Engine Calibration to Enhance RDE Performance

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Background

- Concept of model based simulation environment

Vehicle simulation model
- Vehicle model
- Driver model
- Route model
- Traffic model

Application results in RDE-compliant powertrain development

Summary
New Civic diesel

**Fuel economy (CO₂) Modified NEDC**
- 91 g/km (6MT, Sedan)
- 93 g/km (6MT, Hachback)
- 109 g/km (9AT)

**Exhaust emissions**
- Euro6d-TEMP

Civic

Passed RDE regulation and achieved 91 g/km
### RDE definition

<table>
<thead>
<tr>
<th></th>
<th>Chassis dynamometer</th>
<th>RDE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle speed profile</td>
<td>Fixed</td>
<td>Depends on vehicle, driver, route, and traffic</td>
</tr>
<tr>
<td>Environment (Ta, Pa)</td>
<td>Fixed</td>
<td>Depends on season, weather, wind, and altitude</td>
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<tr>
<td>Road load force</td>
<td>Straight, w/o gradient (w/o PEMS)</td>
<td>Depends on curves, altitude, road surface, passengers, and baggage (with PEMS)</td>
</tr>
<tr>
<td>Repeatability</td>
<td>with</td>
<td>w/o</td>
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</table>

Difficult to check RDE performance at all conditions during development
## Method for RDE simulation and calibration

### Necessity of model utilization for efficient development

<table>
<thead>
<tr>
<th>Tests on road</th>
<th>Chassis dynamometer (vehicle) + vehicle simulation</th>
<th>Engine test bed (engine) + vehicle simulation</th>
<th>Model (engine) + vehicle simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PEMS</strong></td>
<td><img src="image1" alt="Chassis dynamometer" /> <img src="image2" alt="Vehicle simulation" /></td>
<td><img src="image3" alt="Engine test bed" /> <img src="image4" alt="Vehicle simulation" /></td>
<td><img src="image5" alt="Model simulation" /> <img src="image6" alt="Vehicle simulation" /></td>
</tr>
<tr>
<td><strong>Vehicle simulation</strong></td>
<td>Consideration of road load force change due to curves, altitude, road surface (weather, wind), driver behavior, and traffic conditions</td>
<td><strong>EiL (Engine in the loop)</strong></td>
<td><strong>MiL (Model in the loop)</strong></td>
</tr>
</tbody>
</table>

**Validation in real world**

- Easy to simulate and calibrate
Background

**Concept of model based simulation environment**

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Application results for RDE compliant powertrain development

Summary
RDE-compliant engine development method

Engine calibration timeline

- First engine
- First vehicle
- Engine hardware fix
- Engine software fix
- Validation phase
- SOP

Vehicle tests in (environmental) chassis dynamometer
Vehicle tests on road with PEMS

Engine bench tests (EiL: Engine in the loop)
- Vehicle model (virtual)
- Target vehicle speed
  - Fixed (NEDC, WLTC, etc) profile
  - Vehicle simulation output profile

Model based simulation (MiL: Model in the loop)
- Engine simulation environment
  - ECU model
  - Combustion model
  - Catalyst model
- Vehicle simulation environment
  - Vehicle model
  - Driver model
  - Route model
  - Traffic model

Vehicle simulation for engine hardware/calibration fix and RDE validation
Flowchart of model utilization

Coupling of vehicle simulation and engine simulation

Vehicle simulation
- (NEDC, WLTC, RDE)
- Vehicle model
- Driver model
- Route model
- Traffic model

Engine simulation
- Synthetic gas flow test bed
- ECU model
- Catalyst model

Verification
- Vehicle test

Experiment definition
- Boundary finder
- Dynamic DoE
- Transient measurement (environmental engine bench)

Dynamic statistical combustion model

Calibration target
- Base maps, environmental corrections, controllers, aftertreatment control etc.

Simulation and optimization

Verification

Vehicle simulation

Route
- Rural
- Motorway
- Urban

Altitude
**Predictive accuracy of engine model**

Achievement of quantitative emissions prediction at RDE

- **Vehicle speed**
- **Engine outlet**
- **Tailpipe**

**NOx (mg/s)**
- Measurement
- Simulation

**Soot (mg/s)**
- Measurement
- Simulation

**gfuel (g/s)**
- Measurement
- Simulation

Model input: engine speed, brake torque, coolant temp., ambient temp., and ambient pressure
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Road load force of vehicle model

Model input: Vehicle specification (F0, F1, F2)

Confirmation of the road load force accuracy by coasting simulation
Predictive accuracy of NEDC simulation

Engine speed and torque are well simulated (gear shift profile is given)
Predictive accuracy of WLTC simulation

Model input: Vehicle specification (F0, F1, F2)
Target vehicle speed profile

Engine speed and torque are well simulated (gear shift position is calculated)
Statistical analysis with big driving data

Vehicle speed distribution

Acceleration / deceleration distribution

Gear shift up timing distribution

Extraction of driver behavior to reproduce real driving
Influence of driver model parameter on dynamic behavior

- **Max. acceleration**
- **Max. shift up engine speed**
- **Max. acceleration & shift up engine speed**

V*a pos: Vehicle speed multiplied by maximum positive acceleration

RPA: Relative positive acceleration

Succeed in targeting assumed driver characteristics
Route models for RDE performance validation

Introduction of detailed digital map information (traffic sign, curve, altitude)
Utilization of stochastic based traffic model to reproduce real driving
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Vehicle simulation for RDE route

Generation of vehicle speed by vehicle, driver, route, and traffic models
Vehicle speed profiles at RDE conditions are well expressed in simulation.
Driving characteristics at RDE

Realization of vehicle simulation within RDE dynamic criteria regulation
Simulation

9AT transmission model

Introduction of automatic transmission logic in the vehicle simulation
Model based RDE performance evaluation

Vehicle, driver, route, and traffic models

Vehicle speed, engine speed, brake torque, and gear shift position

NOx, Soot, CO₂ etc.

Vehicle simulation

Engine simulation

Achievement of emission prediction with vehicle and engine simulation
Evaluation of emission robustness

Validity confirmation of hardware selection and calibration data settings

Realization of model-based validation before actual measurement
It is a challenge to sufficiently validate RDE performance under all conditions through road tests during vehicle development due to wide range of validating conditions.

A model based development technology was established to simulate, verify and calibrate the emissions performance of a vehicle.

RDE performance could be accurately predicted by coupling a vehicle driving simulation with an engine simulation that includes an ECU model, combustion model (dynamic data based statistical model), and exhaust aftertreatment catalyst model.

Use of the simulation model enabled robust validation of RDE performance under various conditions that assume driving on actual roads.