Interpretation tools and concepts for the heat management in the drive train of the future

S. Klopstein / Dr. S. Lauer / Dr. F. Massen

GT Conference 2010, Frankfurt
FEV’s integrated thermal management in powertrains

Content

- Motivation
- Main features of the FEV 1D-simulation model
- Calibration and verification
- Fuel reduction potential and interactions of different thermal management measures
- Cooling system development of HEV and EV
FEV’s integrated thermal management in powertrains

Motivation

- Engine: inline 4 cylinder
- SI displacement: 2.0 l
- Power: 110 kW
- Vehicle: small SUV
- Transmission: 6 gear (manual)
- Vehicle weight: 1560 kg
- Drag coefficient: 0.38

![Graph showing engine speed vs. time and fuel consumption vs. time](image_url)
FEV’s integrated thermal management in powertrains

Content

- Motivation
- Main features of the FEV 1D-simulation model
- Calibration and verification
- Fuel reduction potential and interactions of different thermal management measures
- Cooling system development of HEV and EV
**FEV’s integrated thermal management in powertrains**

**Main features of the model**

- The FEV thermal management model is based on the commercial 1D computer code GT-Suite (Gamma Technologies) with special features implemented:
  - Discretization of the engine into the relevant thermal inertias
  - Separate models for cooling and oil circuit, which are coupled at the relevant thermal interfaces
  - Heat flows depending on engine operating point and especially their engine internal distribution
  - Detailed engine friction model with special attention to the local boundary conditions (e.g. local oil temperature at liner)
FEV’s integrated thermal management in powertrains
Main features of the model

- Highly flexible structure of FEV’s simulation model enables development and investigation of thermal management measures such as
  - Split cooling, integrated exhaust manifold
  - Electric coolant or oil pumps, map controlled thermostat etc.
  - Oil cooler, gear box oil cooler
  - Heat accumulator (e.g. PCM for oil or water), auxiliary heater
  - Exhaust gas heat recovery (exhaust gas heat exchanger)
  - Insulation of engine, flaps or blinds for air guiding
  - Switchable cooling jets (and variable oil pump)
  - Switchable degas bottle
- Also worst case scenarios can be investigated such as
  - Virtual cooling system testing
  - Engine full load operation with cold engine start.
- All investigations can be done for any driving cycle and start / ambient temperature
FEV’s integrated thermal management in powertrains
Structure of the simulation model: main model

Thermodynamics of the engine: calculation of required engine power and fuel consumption

Vehicle and Environment

Sub model “friction”

Sub model Oil Circuit

(RH Cylinder Block) Liner Outer Block

(RH Cylinder Head) Flame Deck Outer Part

(Flame Deck Outer Part)

(LH Cylinder Head)

Luine Outer Block

(LH Cylinder Block)

Calculation of the heat input into the engine with mappings and empiric relations
FEV’s integrated thermal management in powertrains

Structure of the simulation model: main model

- Sub model: Controlling
  - Speed of fan = f (T_{Fluid}, pme)
  - Speed of coolant pump = f (T_{Fluid}, pme)
  - Lift of thermostat = f (T_{Fluid}, pme)

- Sub model: Accessories
  - Driving torque of fan
  - Driving torque of coolant pump
  - Driving torque of electric generator
  - Driving torque of A/C compressor

- Sub model: Friction
  - Piston group friction = f (rpm, T_{Liner})
  - Load correction piston group = f(BMEP, rpm)
  - Crankshaft friction = f (rpm, T_{Gallery})
  - Valve train friction = f (rpm, T_{Gallery})
  - Power of the oil pump = f (rpm, T_{Oil Sump})

- Sub model: Oil circuit
  - Oil flow crankshaft = f (rpm, T_{Oil after Oil cooler})
  - Oil flow piston cooling jet = f (rpm, T_{Gallery})
  - Oil flow cylinder head = f (rpm, T_{Oil after Oil cooler})
  - Etc.

Optional sub models:
- Hybrid modul
- Battery modul
- Automatic transmission
FEV’s integrated thermal management in powertrains

Content

- Motivation
- Main features of the FEV 1D-simulation model
- Calibration and verification
- Fuel reduction potential and interactions of different thermal management measures
- Cooling system development of HEV and EV
FEV’s integrated thermal management in powertrains

Engine and vehicle data

- Engine: inline 4 cylinder SI
- Displacement: 1.6 l
- Power: 80 kW
- Vehicle: B-segment
- Transmission: 5 gear (manual)
- Vehicle weight: 1060 kg
- Drag coefficient: 0.36
- Vehicle frontal area: 1.9 m²
FEV’s integrated thermal management in powertrains
Comparison of meas. and calc. oil & coolant temperatures

- Simulation
- Measurement
- $T_{\text{Coolant out}}$
- $T_{\text{Oil-Filter}}$

Time [sec]
Temperature [°C]
Speed [km/h]
FEV’s integrated thermal management in powertrains
Comparison of meas. and calc. part temperatures

[Graph showing speed vs. time and temperature vs. time with lines indicating simulation and measurement for different parts and conditions.]
FEV’s integrated thermal management in powertrains
Calculated friction FMEP vs. time
FEV’s integrated thermal management in powertrains

Content

- Motivation
- Main features of the FEV 1D-simulation model
- Calibration and verification
- Fuel reduction potential and interactions of different thermal management measures
- Cooling system development of HEV and EV
FEV’s integrated thermal management in powertrains
Investigation of different thermal management measures

- Fuel reduction potential and interactions of different thermal management measures:

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>engine:</td>
<td>inline 4 cylinder SI</td>
</tr>
<tr>
<td>displacement:</td>
<td>2,0 l</td>
</tr>
<tr>
<td>power:</td>
<td>113kW</td>
</tr>
<tr>
<td>vehicle:</td>
<td>small SUV</td>
</tr>
<tr>
<td>transmission:</td>
<td>6 gear (manual)</td>
</tr>
<tr>
<td>vehicle weight:</td>
<td>1525 kg</td>
</tr>
<tr>
<td>drag coefficient:</td>
<td>0,36</td>
</tr>
<tr>
<td>vehicle frontal area:</td>
<td>2,68 m²</td>
</tr>
</tbody>
</table>
FEV’s integrated thermal management in powertrains
Investigation of different thermal management measures

- temp. water (basis)
- temp. oil (basis)

- Stop-start system (SS)

- thermal management measures
  - gear box oil cooler (GOC)
  - oil cooler (OC)
  - map controlled thermostat (MCT)
  - integr. manifold (IMan)

- fuel consumption reduction [%]

- time [sec]
FEV's integrated thermal management in powertrains
Investigation of different thermal management measures

- **Engine:**
  - Engine: inline 4 cylinder SI
  - Displacement: 2.0 l
  - Power: 113 kW

- **Vehicles:**
  - **Compact SUV**
    - Vehicle: Compact SUV
    - Transmission: 6 gear (manual)
    - Vehicle weight: 1525 kg
    - Drag coefficient: 0.36
    - Vehicle frontal area: 2.68 m²
  - **C-segment**
    - Vehicle: C-segment
    - Transmission: 6 gear (manual)
    - Vehicle weight: 1280 kg
    - Drag coefficient: 0.32
    - Vehicle frontal area: 2.2 m²

- **Driving cycles:**

```
<table>
<thead>
<tr>
<th>Speed [km/h]</th>
<th>Time [sec]</th>
</tr>
</thead>
<tbody>
<tr>
<td>NEDC (11km)</td>
<td>150-160</td>
</tr>
<tr>
<td>AMS (91km)</td>
<td>50-150</td>
</tr>
</tbody>
</table>
```

© by FEV – all rights reserved. Confidential – no passing on to third parties
FEV’s integrated thermal management in powertrains

Summary: fuel consumption regarding different vehicles

<table>
<thead>
<tr>
<th>Engine</th>
<th>Inline 4 cylinder SI (2.0 l / 113 kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle</td>
<td>Compact SUV</td>
</tr>
<tr>
<td>Transmission</td>
<td>6 gear (manual)</td>
</tr>
<tr>
<td>Weight</td>
<td>1525 kg</td>
</tr>
<tr>
<td>Drag Coefficient</td>
<td>0.36</td>
</tr>
<tr>
<td>Frontal Area</td>
<td>2.68 m²</td>
</tr>
<tr>
<td>Weight</td>
<td>C-segment</td>
</tr>
<tr>
<td>Drag Coefficient</td>
<td>0.32</td>
</tr>
<tr>
<td>Frontal Area</td>
<td>2.2 m²</td>
</tr>
</tbody>
</table>

Fuel consumption [%]:
- Base
- MCT
- OC
- GOC
- OC+GOC
- OC+MCT
- GOC+MCT
- OC+GOC+MCT

w/o integr. manifold in NEDC
FEV’s integrated thermal management in powertrains
Summary: fuel consumption regarding different cycles

![Graph showing fuel consumption comparison across different cycles and vehicles](chart.png)
FEV’s integrated thermal management in powertrains

Content

- Motivation
- Main features of the FEV 1D-simulation model
- Calibration and verification
- Fuel reduction potential and interactions of different thermal management measures
- Cooling system development of HEV and EV
FEV’s integrated thermal management in powertrains

Requirements of electric & electronic components

- Next generation of vehicles will be equipped with hybrid (electric & combustion engine) or electric powertains.
- Additional cooling circuits in HEV (e.g. for electric motor and battery cooling).
FEV’s integrated thermal management in powertrains
Simulation model: increasing complexity

Increasing system complexity

**Cell**
- Heat transfer simulation
- Calculation of temperature distribution in cell
- Coupling with 1D electrochemical model
- Optimization of cell geometry
- Correlation of measured and simulated results

**Module**
- Investigation of critical cells
- Calculation of temperature distribution in module
- Heat transfer from module to cooling circuit
- Optimization of
  - Cooling concept
  - Coolant / refrigerant
  - Material selection

**Cooling System**
- Cooling system development
  - Integration in existing systems (cooling or A/C circuit)
  - Dimensioning of components
- Optimization of thermal management strategies (e.g. heating at cold start)

© by FEV – all rights reserved. Confidential – no passing on to third parties
FEV’s integrated thermal management in powertrains Module Concept Investigation with GT Cool 3D

Concept 1

Concept 2

Condenser

HT Rad.

LT Rad.

CAC

Condenser

HT Rad.

LT Rad.

CAC

© by FEV – all rights reserved. Confidential – no passing on to third parties
FEV’s integrated thermal management in powertrains
Results of Module Concept Investigation with GT Cool 3D

Boundaries for Simulation:
- Ambient Temperature: 25 °C
- Vehicle Speed: 100 km/h
- Condenser Heat rejection: 8 kW constant
- CAC int. Mass Flow / Temperature / Pressure: 300 kg/h / 120 °C / 1.8 bar abs.
- LT int. Vol. Flow / Temperature: 30 l/min / 50 °C

Heat Flow
- Heat Flow Percentage [%]
  - Module Concept 1
  - Module Concept 2

Air Mass Flow
- Air Mass Flow Percentage [%]
  - Module Concept 1
  - Module Concept 2
FEV’s integrated thermal management in powertrains
Results of Module Concept Investigation with GT Cool 3D
Interpretation tools and concepts for the heat management in the drive train of the future

Thank you for your interest!