Thermal Management Optimization of Hybrid Vehicles in GT-SUITE

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Verification & Analysis
MAHLE Powertrain
Optimized Thermal Management For Hybrid Vehicles

Motivation

MAHLE Powertrain is an Engineering Services Provider
Evolving customer needs

Customer Requests
Various request types
- Performance evaluation
- EV range estimation
- Optimal HEV Layout
- Drive cycle efficiency
- Battery life estimations

Customer Applications
Combinations of
- EV / HEV / ICE only
- P0 / P1 / P2 / P3 / P4
- FWD / RWD / AWD

Customer Demands
Project variability
- Accurate results
- Quick turn-around
- Flexible
Optimized Thermal Management For Hybrid Vehicles

New Full Vehicle Thermal Model

Our Solution

- Drive Cycle Model
- Engine Friction
- Engine Thermal
- Engine Lubrication
- Engine Cooling
- Airside Cooling
- Transmission Friction
- Transmission Lubrication & Thermal
- Electrical
- HVAC
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Presentation Overview

- Modelling
  - Generic Drive Cycle Model
  - Engine Thermal Model
- Case study
  - DI3 Hybrid Electric Vehicle Thermal Management
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Generic HEV Model

- Powertrain type
  - ICE
  - P0/P1/P2/P3/P4

- Architecture options
  - FWD
  - RWD
  - 4WD

- Individual gearing options
  - Transfer box
  - Gearbox
  - Final Drive

- Specific powertrain selection for
  - ICE only
  - HEV
  - EV
Generic HEV Model

Controllers

How to control the Generic HEV Model

- Model User
  - Powertrain layout selection
  - Strategy definition

- Driver and torque split controllers
  - Driver calculates torque request
  - Strategy
    - MGU / ICE operation
  - Specific MGU and/or ICE torque passed onto component
## Optimized Thermal Management For Hybrid Vehicles

### Generic HEV Model

**Strategy Controller**

#### Modes

- **Mode 1**: Engine Only
- **Mode 2**: EV only
- **Mode 3**: HEV Series
- **Mode 4**: HEV Parallel

#### Transition Conditions

- **Mode 1**
- **Mode 2** ↔ **Mode 3** ↔ **Mode 4**

#### Strategy Components

- **ICE Operation**
- **MGU(s)**
- **Clutch**
- **USER INPUT**

- 12bar
- P3
- Locked

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New Full Vehicle Thermal Model
Drive Cycle Model Correlation

- RDE facility is ideal test environment for Drive Cycle Model correlation
  - Maximum altitude of 5km
  - Climatic range: -40 to +60°C / 10 – 80% relative humidity

- Cumulative fuel flow shows good correlation between simulation and vehicle test results

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![Graph showing correlation between test and simulation](image-url)
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New Full Vehicle Thermal Model

Drive Cycle Model

Engine Friction

Engine Thermal

Transmission Friction

Engine Lubrication

Transmission Lubrication & Thermal

Engine Cooling

Electrical

Airside Cooling

HVAC
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New Full Vehicle Thermal Model

Engine Thermal Model
- Ease of implementation within Full Vehicle Model
- Fast-running
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New Full Vehicle Thermal Model

Thermal Model Correlation

- The initial correlation results showed model confidence
- Heat flows predicted in the 1D thermal model matched
  - Indimaster / Dyno results
  - CFD / Converge predictions

- Metal temperatures showed a good correlation between the CFD and the 1D FE Cylinder
  - E.g. both sides of the cylinder head fire face
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Thermal Management Optimization of Hybrid Vehicle
Case Study

MAHLE DI3 Engine

P0 / P3 hybrid

Compact battery

B Segment Vehicle

WLTP Cycle
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**Optimized Thermomanagement**
**Considered Warm-Up Technologies**

**MAHLE DI3 1.2L ICE**
- LP EGR

**Baseline**
- Mechanical water pump
- Conventional thermostat
- No warm-up prioritisation

**Warm-up technologies**
- Electric water pump
  - Flow on demand
- Split cooling
  - Stagnant block flow
- Multi flow valve
  - EOC or TOC flow prioritisation
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ICE Only
Warm-Up Improvements

- Head coolant shows slower warm-up
- Faster engine oil warm-up
- Faster gearbox oil warm-up
- Elevated steady-state temperatures

2% fuel economy improvement achieved by thermal management optimisation
Hybrid Mode

Hybrid Strategy

**Strategy**

**Modes**

- Engine Only
- EV

**HEV**

- P3 Load Shift
- P3 Load Assist
- P0/P3 Traction

**Transition Conditions**

Based on:
- SOC
- Power demand
- Braking request

**Engine Load: 12bar**

![Graph showing engine load and speed relationships with different modes and transition conditions.]
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Hybrid Mode
Warm-Up Technologies Included

Hybrid strategy optimisation to minimise warm-up time
10% fuel economy improvement achieved by hybrid strategy
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Results Summary

- Drive Cycle Model
- Engine Friction
- Engine Thermal
- Transmission Friction
- Engine Lubrication
- Engine Cooling
- Transmission Lubrication & Thermal
- Electrical
- HVAC
- Airside Cooling

![Graph showing fuel economy improvements](image-url)
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Example of Toolset Deployment
MAHLE Modular Powertrain

High Voltage PHEV Powertrain
- Engine <210g/kWh min BSFC
- 1/2/4 speed gearbox options
- Scalable hybrid: B to J-Segment
- Drive cycle CO₂ below 2030 proposed target

Development supported with GT-SUITE
- Performance targets
- Vehicle capability targets
- Hybrid mode
- Hybrid strategy
- Mechanical development
Thank you for your attention

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