A New Modular Hybrid Powertrain Concept

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Mike Bassett
Head of Research & Advanced Engineering,
MAHLE Powertrain Limited,
Northampton, UK
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MAHLE Powertrain
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Global Fleet CO₂ Limits

Tailpipe CO₂ targets are driving manufacturers towards increased electrification

Would require pure ICE cycle average brake thermal efficiency to nearly double over next decade

Increasing levels of electrification required

Most appropriate technology for the near to medium term?

EU 2021: 95 g/km

EU 2030: 59 g/km

UK gasoline & diesel ban by 2035?

Peugeot electric mandatory by 2045?

Targets based on 1400 kg vehicle mass for “average vehicle”

Source: ICCT Jan 2019 CO₂ Emission Standards for Passenger Cars and Light-commercial Vehicles in the European Union
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Holistic and transparent analysis of CO₂ emissions

Sources of CO₂ emissions for different powertrains

A life-cycle analysis is a much better reflection of actual CO₂ emissions

* No actual source of CO₂ emissions, however energy losses
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Vehicle life-cycle CO₂
Is there an optimal battery size for a PHEV?

PHEV – Optimal Battery Size

- Analysis based on typical 1400kg vehicle
- 150,000 km life
- Utility factor based on R101 tail-pipe weighting factor
- Well to tank contribution also considered
- Grid CO₂ intensity for UK
  - 292 g/kWh
- Battery embedded CO₂
  - 175 kg/kWh¹ & ²

PHEVs can offer total life-cycle benefits when compared to BEVs with a large battery

Optimal battery size

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Concept of the MAHLE Modular Hybrid Powertrain

One step further: MAHLE’s scalable and fully integrated modular hybrid powertrain

"MAHLE Dedicated Hybrid Engine"

Two speed BEV powertrain

"MAHLE Integrated Electric Powertrain"

The MMHP offers considerable advantages in terms of cost, complexity, package size and weight
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Driveline architecture

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Parallel Hybrid</th>
<th>Series Hybrid</th>
<th>Dual Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>NVH</td>
<td>0</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Emissions</td>
<td>0</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Operating point efficiency</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Cruising efficiency</td>
<td>0</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>Low speed charging</td>
<td>0</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Stationary charging</td>
<td>0</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Cost of transmission</td>
<td>0</td>
<td>+</td>
<td>0</td>
</tr>
<tr>
<td>Cost of e-components</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Zero emissions zone performance</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Overall</td>
<td>+</td>
<td>++</td>
<td>++</td>
</tr>
</tbody>
</table>

Dual mode hybrid – best of Parallel and Series hybrids plus direct eDrive for seamless torque delivery
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Vehicle performance targets
Example: C-segment compact SUV

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceleration time (0-100 km/h)</td>
<td>(s)</td>
<td>&lt;9.0</td>
</tr>
<tr>
<td>Maximum vehicle speed</td>
<td>(km/h)</td>
<td>&gt;180</td>
</tr>
<tr>
<td>Charge sustaining speed (level road)</td>
<td>(km/h)</td>
<td>&gt;130</td>
</tr>
<tr>
<td>Charge sustaining with 1000 kg trailer</td>
<td>(km/h)</td>
<td>80</td>
</tr>
<tr>
<td>Pure electric driving range (WLTP)</td>
<td>(km)</td>
<td>&gt;80</td>
</tr>
<tr>
<td>Charge sustaining fuel consumption (WLTP)</td>
<td>(L/100 km)</td>
<td>4.9</td>
</tr>
<tr>
<td>Weighted WLTP CO₂</td>
<td>(g/km)</td>
<td>&lt;18</td>
</tr>
</tbody>
</table>

- Vmax and dynamic performance determine motor power and torque
- Charge sustaining speed determines required engine power and highest gear ratio
- Trailer towing targets determine other gear ratios
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Detailed System Simulation
Example: C-segment compact SUV

- Detailed simulation of vehicle operation
  - Generic scalable model
  - Flexible strategy definition

- Quickly optimise system specification
  - Multiple parameters
  - Many driving scenarios

- Guide direction from an early stage
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Operating modes
Example: C-segment compact SUV
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MAHLE Modular Hybrid Powertrain

- MAHLE Dedicated Hybrid Gearbox
- Highly integrated electric components
- 1, 2 or 4 speed gearbox
- Low cost, compact & adaptable
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MAHLE Modular Hybrid Powertrain

MAHLE Dedicated Hybrid Engine (DHE)

Reduced complexity, optimized for hybrid use case

Jet Ignition combustion process

Highest efficiency at lowest cost
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MAHLE Modular Hybrid Powertrain
MAHLE Jet Ignition® (MJI)

- Reduced Burn Duration
- Extends EGR Dilution Limit
- Reduced Knock Tendency
  Enables High CR
- Enables Fuel Consumption < 207 g/kWh
  and Brake Thermal Efficiency > 40 %

Limited DHE operating speed and load range for high charge sustaining efficiency
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Scalable across complete range of vehicles

Modular solution scalable across a wide range of vehicle sizes and performance derivatives

- Compact car
  - 60 kW DHE 1 speed transmission 75 kW* traction motor

- Compact crossover SUV
  - 60 kW DHE 2 or 4 speed transmission 127 kW* traction motor

- Large 4x4 SUV
  - 90 kW DHE 4 speed transmission 190 kW* traction motor

* continuous power
Conclusions

- For many applications plug-in hybridisation an appropriate technology
  - Local emissions free driving
  - Long range capability with small battery

- MAHLE Modular Hybrid Powertrain demonstrates:
  - Cost optimised and integrated approach
  - High efficiency through MAHLE Jet Ignition®
  - Scalable multi-ratio transmission with integrated traction motor and power electronics
  - MAHLE Powertrain’s capabilities
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Thank you

Mike Bassett
MAHLE Powertrain Limited
mike.bassett@gb.mahle.com