Planetary Electric Drive Module with AC Induction Motor

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Planetary Coaxial Drive Module

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Global, localised manufacturing footprint

1) Includes c. 5,700 employees in the China, Taiwan, Australia and Colombia JVs

Source: GKN, Financial Times, Bloomberg, Reuters, Wall Street Journal
World class innovation and engineering capabilities

Our in-house engineering capability…

5 Technical centres

2,124 Engineers¹)
additional 379²) in China SDS JV

1,305 Patents granted
with 567 pending applications

… develops world class innovative technology

World’s first 2-speed disconnecting eAxle

BMW VL3 Driveshaft system

Volvo eAxle

Modular lightweight front propshaft

First AWD system completely designed, integrated and produced in China

eTwinster and eTwinsterX

¹) Including 852 manufacturing engineers; ²) Including 173 manufacturing engineers

Source: GKN
Heritage and Leadership in eDrive Technology

- More than 750,000 vehicles on the road today, using GKN eDrive technology
- Almost each year a new Hybrid & eDrive system has been launched into production
System Overview

Key application data

- Plug-in Hybrid Electric Vehicle
- Compact SUVs and mid sized cars
- Off-road capability
- All-wheel drive with electric P4 module and ICE at the front
- Max. electric vehicle speed 130 kph
- Max. vehicle speed with ICE 210 kph
Coaxial System - Overview

Epicyclic Transmission

- Reduction ratio $i=10.1$ with stepped planets
- Max. input speed 15 500 rpm
- Splash lubrication with advanced oil management
- 2500 Nm output torque
- Open differential

Electric Traction Motor

- Induction motor
- Water cooled
- 250 Nm peak torque
- 250 V – 400 V operation range
- 70 kW peak (10s)
- 20 kW permanent power
- Semi integrated motor design
• Various e-motor types could be used in the coaxial transmission arrangement. Two types of e-motor types have been rated regarding relevant features for this application. Some of these features are listed below.

• Competitive system costs, high speed capability, independence of rare earth materials may dominate the decision process.

<table>
<thead>
<tr>
<th>Transmission e-motor type for hybrid application</th>
<th>PSM (PM-Synchronous Machine)</th>
<th>ASM (Asynchronous Machine)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shown rating is based on GKN e-drive &amp; hybrid experience. These features do have application specific nature.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Packaging and power density</td>
<td>+++</td>
<td>+</td>
</tr>
<tr>
<td>Efficiency performance <strong>including</strong> system losses across driving cycle</td>
<td>+++ / ++ (T↑ &amp; n↓ / T↓ &amp; n↑)</td>
<td>++ / +++ (T↑ &amp; n↓ / T↓ &amp; n↑)</td>
</tr>
<tr>
<td>Manufacturing, robustness &amp; costs</td>
<td>++</td>
<td>+++</td>
</tr>
<tr>
<td>Failsafe without inverter (Back-EMF)</td>
<td>-</td>
<td>+++</td>
</tr>
<tr>
<td>NVH performance</td>
<td>+++</td>
<td>++</td>
</tr>
</tbody>
</table>
System Design – Cross Section

- Lifetime: 240,000 km
- System weight: 73 kg

Key challenge: Thermal system behaviour due to coaxial design combined with induction motor
Thermal System Design – Most Severe Conditions

Simulation Results

- Continuous hill climb and maximum vehicle speed condition result in the highest oil sump temperatures
- Design maximum target temperature exceeded – further optimization required
Maximum Speed
– Verification of Simulation

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-motor speed</td>
<td>15500</td>
<td>rpm</td>
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<tr>
<td>E-motor torque</td>
<td>0</td>
<td>Nm</td>
</tr>
<tr>
<td>Ambient temperature</td>
<td>105</td>
<td>°C</td>
</tr>
<tr>
<td>Cooling EM inlet</td>
<td>75</td>
<td>°C</td>
</tr>
<tr>
<td>Oil amount</td>
<td>800</td>
<td>ml</td>
</tr>
</tbody>
</table>

Verification Results

• Simulation agrees very well with verification test
• Measured oil sump temperature of 157°C exceeds design target – optimisation required
• Temperature simulation model verified for this operation point
Hill-Climb – Verification of Simulation

<table>
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<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-motor speed</td>
<td>2900</td>
<td>rpm</td>
</tr>
<tr>
<td>E-motor torque</td>
<td>64</td>
<td>Nm</td>
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<tr>
<td>Ambient temperature</td>
<td>105</td>
<td>°C</td>
</tr>
<tr>
<td>Cooling EM inlet</td>
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**Verification Results**

- Measured temperature of 110°C fits well to the predicted temperature of 107°C
- Simple E-motor model not suitable to predict sub-component temperatures
- Simulation model was verified on system level and can be used for the system optimisation
High Temperature Oil Selection

Oil screening

- Four potential oil candidates tested in laboratory
- Colour change, viscosity change and neutralization values measured
- Suitable was oil identified and verified in further testing (Oil 1)
System Losses

Main contributors for losses in „Maximum Speed“ condition

• Churning losses
• Motor windage losses
Churning Losses

Reduction of churning losses

• Low viscosity oil
• Lowering oil level – significant impact, test showed a temperature reduction of 35% when the oil level was reduced by 30%
• Fluidic optimisation
Lubrication concept

- Rotation of planetary gear set feeds oil into distribution cascade
- Internal channels feed some of this oil to bearings and sealings
- Remaining volume flows through external pipe to motor B-shield bearing and seal
- Motor shaft conical geometry forces oil back into gearbox
Thermal Management

System Cooling

- Cooling capacity of the electric motor is able to transfer the total system losses.
- Motor A-shield geometry is used as heat exchanger to cool the gearbox.
- Open surface of transmission is cooled in addition by forced air due to vehicle speed or free convection when vehicle is at stand still.
Exchange of the open differential for a GKN Twinster module allows to add full torque vectoring capability to the electric drive module.
Performance Optimisation

Virtual Transmission Engineering

- Define the optimum transmission concept
- Optimise the system performance parameters by simulation and verify with physical tests.

Transmission system footprint related to fatigue, efficiency and NVH
Summary

Key Points

• GKN’s deep in-house technical expertise together with more than 15 years series production experience in e-drive applications helped to achieve the demanding programme targets.

• Systems Engineering Methods were used to develop and industrialize the product simultaneously in two markets – Europe and China.

• The development of a bespoke product tailored to the customer requirements ensures that the requirements and expectations are met in an optimum way.
Global Leader in traditional and electrified drivelines