State of the Art Development Methodologies for Hybrids and e-Drives

29.11.2018 PDiM 18, Chalmers Conference Centre
Content

Introduction

Technology selection - *Do the right thing*

Validation of new design concepts – *Do the things right*

Integrated design verification

Summary and outlook
Content

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Technology selection - *Do the right thing*

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Summary and outlook
AVL – Transmission Overview

Concept / Structure
Transmission synthesis, Specification, Dimensioning

Detail Design & Analysis
CAD Design
Structural and dynamic analysis

Software & Controls
Specification & coding
Safety

Calibration
ACT – test bed calibration
In-vehicle calibration
DRIVE™ evaluation

Integration & Testing
Rig and vehicle testing
AVL – Transmission Overview

CURRENT NUMBER OF EMPLOYEES: 400
Electrification and ICE offer quite complementary characteristics

Key Features of Conventional (ICE) and Battery Electric Powertrain (BEV)

- Pollutants
  - CO₂ - Tank to wheel
  - CO₂ - Lifetime - EU mix
  - CO₂ - Lifetime - China mix
- Refueling / Charging time
- Weight / Range
- Cost / Range
- Low speed performance
- High speed performance
- Transients
- NVH

Total cost of ownership (actual status)

Electrification and ICE offer quite complementary characteristics
Content

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Summary and outlook
Overview typical EV-Drive Architectures

<table>
<thead>
<tr>
<th></th>
<th>LAYSHAFT Co-Axial</th>
<th>LAYSHAFT Offset</th>
<th>PLANETARY GEAR Co-Axial</th>
<th>PLANETARY GEAR Offset</th>
</tr>
</thead>
<tbody>
<tr>
<td>Packaging</td>
<td><img src="image1" alt="Diagram" /></td>
<td><img src="image2" alt="Diagram" /></td>
<td><img src="image3" alt="Diagram" /></td>
<td><img src="image4" alt="Diagram" /></td>
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<tr>
<td>Complexity</td>
<td><img src="image5" alt="Diagram" /></td>
<td><img src="image6" alt="Diagram" /></td>
<td><img src="image7" alt="Diagram" /></td>
<td><img src="image8" alt="Diagram" /></td>
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<tr>
<td>Efficiency</td>
<td><img src="image9" alt="Diagram" /></td>
<td><img src="image10" alt="Diagram" /></td>
<td><img src="image11" alt="Diagram" /></td>
<td><img src="image12" alt="Diagram" /></td>
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<tr>
<td>NVH</td>
<td><img src="image13" alt="Diagram" /></td>
<td><img src="image14" alt="Diagram" /></td>
<td><img src="image15" alt="Diagram" /></td>
<td><img src="image16" alt="Diagram" /></td>
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<tr>
<td>Cost</td>
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<td><img src="image18" alt="Diagram" /></td>
<td><img src="image19" alt="Diagram" /></td>
<td><img src="image20" alt="Diagram" /></td>
</tr>
</tbody>
</table>

- **Packaging**: Co-Axial > Offset
- **Complexity**: Offset > Co-Axial, Offset
- **Efficiency**: Co-Axial > Offset
- **NVH**: Offset > Co-Axial, Offset
- **Cost**: Offset > Co-Axial, Offset
EV-Drive Transmissions
Influence of subsystem parameters

E-motor for 1-Speed transmission:
• **max. torque 313 Nm**
• max. power 70 kW

E-motor for 2-speed transmission:
• **max. torque 170 Nm**
• max. power 70 kW
Efficiently identify product design parameters, that perfectly meet technological and monetary customer requirements.

Minimize development time with maximum possible product maturity.
Content

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Integrated design verification

Summary and outlook
AVL Validation Methodology DVP&R

Requirements Engineering

Failure mode analysis
System analysis on component level to determine failure modes and damaging operation

Design Verification Plan & Report

FMEA

CAE

Reports

Testing

Simulation

Verification / Validation
Test specification

Failure mode based test program

Damage Calculation

Verification / Validation

Design Verification Plan & Report

FMEA

CAE

Reports

Testing

Simulation

Verification / Validation
Test specification
Duty Cycle Generation

Input definition
- Markets
- Lifetime targets
- Road profile distribution
- Vehicle simulation input data definition
- Reference customer load duty cycle

Load data generation
- Track Profile selection
- AVL CRUISE simulation
- System analysis
- Damage calculation

Duty cycle definition
- Evaluation & balancing of part specific damages
- Duty cycle definition
- Design duty cycle verification
- Test program generation
Duty Cycle Generation - WORKFLOW

REFERENCE CUSTOMER BEHAVIOR

LIFETIME TARGET
CONVENTIONAL DRIVING, WOT ACC., REVERSE DRIVING, ...

TESTING BOUNDARIES for DC
- SYNTHETIC LOAD DATA
- SYSTEM and DYNO LIMITATIONS

DAMAGE CALCULATION

BALANCING
DETERMINATION OF TEST TIME FOR EACH DC LOAD POINT TO CAPTURE THE REFERENCE DAMAGE

\[ D_{REF} \quad \dot{D}_{DC} \]

\[ D_{DC} = \dot{D}_{DC} \cdot t_{DC} \]

DUTY CYCLE

Abbreviation:
DC ... duty cycle
\( D_{REF} \) ... reference damage
\( D_{DC} \) ... duty cycle damage
\( \dot{D}_{DC} \) ... duty cycle damage rate
\( t_{DC} \) ... time to reach

- Design verification
- Testing
Duty Cycle generation
Detail Reference Customer

Customer Input:

Life time target: 300,000 km

Additional – Korea Market

<table>
<thead>
<tr>
<th>S.no</th>
<th>Item</th>
<th>Percentage distribution</th>
<th>Percentage distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>General road (Included up and down hill curve road)</td>
<td>40% (Smooth city)</td>
<td>50% (Smooth city)</td>
</tr>
<tr>
<td>2</td>
<td>City</td>
<td>30% (Rough city)</td>
<td>20% (Rough city)</td>
</tr>
<tr>
<td>3</td>
<td>High way</td>
<td>20%</td>
<td>20%</td>
</tr>
<tr>
<td>4</td>
<td>Off road</td>
<td>10% (Non paved)</td>
<td>10% (Non paved)</td>
</tr>
</tbody>
</table>

Percentage split into Urban and Sub Urban

Highway directly transferred

Non Paved directly transferred in Off-Road percentage

Altitude profiles are included in some of the used track profiles

Day and night operation is not considered in simulation

AVL Usage Space Definition

Road Profile Type

<table>
<thead>
<tr>
<th></th>
<th>India</th>
<th>Europe</th>
<th>Korea</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban</td>
<td>%</td>
<td>Distance [km]</td>
<td>%</td>
</tr>
<tr>
<td>Sub Urban</td>
<td>55%</td>
<td>165000</td>
<td>50%</td>
</tr>
<tr>
<td>Highway</td>
<td>20%</td>
<td>60000</td>
<td>15%</td>
</tr>
<tr>
<td>Off-Road</td>
<td>10%</td>
<td>30000</td>
<td>5%</td>
</tr>
<tr>
<td>Sum</td>
<td>100%</td>
<td>300000</td>
<td>100%</td>
</tr>
</tbody>
</table>

Special Maneuvers

<table>
<thead>
<tr>
<th></th>
<th>Total Number</th>
<th>Distance [km]</th>
<th>Total Number</th>
<th>Distance [km]</th>
<th>Total Number</th>
<th>Distance [km]</th>
</tr>
</thead>
<tbody>
<tr>
<td>WOT 0-v max kph</td>
<td>5000</td>
<td>5000</td>
<td>5000</td>
<td>5000</td>
<td>5000</td>
<td>5000</td>
</tr>
<tr>
<td>Driving - R</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>μ-Transient</td>
<td>500</td>
<td>150</td>
<td>750</td>
<td>750</td>
<td>1500</td>
<td>1500</td>
</tr>
<tr>
<td>Hill-Start</td>
<td>250</td>
<td>250</td>
<td>250</td>
<td>250</td>
<td>250</td>
<td>250</td>
</tr>
</tbody>
</table>

Percentage split into Urban and Sub Urban

Highway directly transferred

Non Paved directly transferred in Off-Road percentage

Life time target: 300,000 km
System analysis

Duty Cycle generation
Detail Damage calculation models

Failure mode definition

<table>
<thead>
<tr>
<th>Failure Modes</th>
</tr>
</thead>
<tbody>
<tr>
<td>[311-1] HCF - bending input shaft S1</td>
</tr>
<tr>
<td>[312-1] HCF coast - tooth root gear G11</td>
</tr>
<tr>
<td>[312-2] Wear coast - tooth flank gear G11</td>
</tr>
<tr>
<td>[312-3] HCF drive - tooth root gear G11</td>
</tr>
<tr>
<td>[312-4] Wear drive - tooth flank gear G11</td>
</tr>
<tr>
<td>[312-1] HCF - ball bearing B11</td>
</tr>
<tr>
<td>[312-2] Wear - ball bearing B11</td>
</tr>
<tr>
<td>[313-1] HCF - roller bearing B12</td>
</tr>
<tr>
<td>[411-0] HCF - bending intermed shaft S2</td>
</tr>
<tr>
<td>[411-1] HCF coast - tooth root gear G21</td>
</tr>
<tr>
<td>[411-2] Wear coast - tooth flank gear G21</td>
</tr>
<tr>
<td>[411-3] HCF drive - tooth root gear G21</td>
</tr>
<tr>
<td>[411-4] Wear drive - tooth flank gear G21</td>
</tr>
<tr>
<td>[412-1] HCF coast - tooth root gear G23</td>
</tr>
<tr>
<td>[412-2] Wear coast - tooth flank gear G23</td>
</tr>
<tr>
<td>[412-3] HCF drive - tooth root gear G23</td>
</tr>
<tr>
<td>[412-4] Wear drive - tooth flank gear G23</td>
</tr>
</tbody>
</table>

Example: Failure mode activation methodology

<table>
<thead>
<tr>
<th>SUBSYSTEM</th>
<th>FAILURE MODE</th>
<th>FAILURE LOCATION</th>
<th>CAUSE OF FAILURE</th>
<th>EFFECT ON SYSTEM</th>
<th>ACTIVATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input Shaft / Gear in</td>
<td>Wear (fracture fatigue)</td>
<td>Tooth flank</td>
<td>Mech. load (poor lubrication, pitting)</td>
<td>NVH → Damage of transmission</td>
<td>High load operation</td>
</tr>
</tbody>
</table>
**DVP Input - Damage Calculation**

**Input**
- Test cycles
- Reference cycles

**Damage model**
- Model calibration
  - "Real world" damage measurement
  - Simulations

**Output**
- \( \dot{D} \) Damage rate (Damage per hour)

LOAD TRANSFER FUNCTION:

\[
\text{Contact Stress} = f(\text{Torque}_{EM})
\]

DAMAGE CALCULATION

\[
D_i = f(\text{Contact Stress})
\]

- \( AF \) ... Acceleration factor
- \( \dot{D} \) ... Damage rate

\[
\dot{D}_{Test} = \frac{1}{t_{Test}} \sum D_i
\]

\[
AF = \frac{\dot{D}_{Test}}{\dot{D}_{Ref}}
\]

\[
\dot{D}_{Ref} = \frac{1}{t_{Ref}} \sum D_i
\]
Online Target Monitoring
Test procedure / measured test cycle vs. reference

Input

Damage model

Output

MATHEMATICAL EXPRESSION

\[ D_i = f(U_i, M_i, T_{amb_i}, \ldots) \]

Online comparison of damage from reference (target damage) to test cycles

Model calibration
- “Real world” damage measurement
- Simulations

Rel. accumulated Damage

- test cycle does not reach the validation target, test cycle has to be modified

- test cycle reaches the validation target, test cycle modification

- target damage accumulation line

- test cycle reaches the validation target, target reached!
Result – Comparison
Normalized damage

The lowest ratio is most demanding for the design. Excepting damage modes are:

- Ratio 9,91 HCF tooth root G11 drive/coast
- Ratio 9,3 HCF coast tooth root G21
- Ratio 8,27 HCF tooth root gear G21 drive/coast.
Result – Test Program
Damage normalized on market

The comparison is based on the calculated damage

<table>
<thead>
<tr>
<th>LP</th>
<th>Time (h)</th>
<th>Input Speed (rpm)</th>
<th>Input Torque (Nm)</th>
<th>Power (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LP1</td>
<td>90</td>
<td>12500</td>
<td>110</td>
<td>144</td>
</tr>
<tr>
<td>LP2</td>
<td>55</td>
<td>5500</td>
<td>-250</td>
<td>-144</td>
</tr>
<tr>
<td>LP3</td>
<td>14</td>
<td>3500</td>
<td>400</td>
<td>146,6</td>
</tr>
<tr>
<td>LP4</td>
<td>5</td>
<td>15000</td>
<td>50</td>
<td>78,5</td>
</tr>
<tr>
<td>LP5</td>
<td>120</td>
<td>5500</td>
<td>150</td>
<td>86,4</td>
</tr>
<tr>
<td>LP6</td>
<td>30</td>
<td>9500</td>
<td>-150</td>
<td>-149,2</td>
</tr>
<tr>
<td>LP7</td>
<td>300</td>
<td>9500</td>
<td>150</td>
<td>149,2</td>
</tr>
<tr>
<td>LP8</td>
<td>10</td>
<td>-1500</td>
<td>-270</td>
<td>42,4</td>
</tr>
</tbody>
</table>

Test Time: 714 h

LP
Test Program MET150 $i=9,91$

RAD (relative accumulated damage)

Synthetic balancing on failure mode based testing

Test Program balancing was carried out respecting the following boundary conditions:
- Max. RAD < 1,85
- Min. RAD < 0,85
Correlation between RIG Testing, DVP&R and FMEA

1. Collection of simulation data

2. Definition of test cycle structure *)

3. Segmentation of simulation data

4. Load analysis Characterization of segments

5. Selection of relevant segments

6. Assembly of test cycle

Content of important LCT operating conditions

- **Part/component**
  - Damaging operation
  - Aggravating conditions
  - Conclusion (cycle needs to contain...)

**Input shaft**
- High ICE torque
- Torque irregularities (low engine speed)
- Missalignment; inbalance
- High ICE load at low speeds (LPM)
- Needle bearings
- Open C0
- Closed C0 (no relative speed)
- High speed difference input/output
- Low lube oil flow
- High oil temp
- Missalignment; runout
- High amount of pure electric driving

**Output shaft**
- High torque ICE + EM
- Missalignment; inbalance; runout
- Boost operation
- Hydr. seal rings
- High apply pressure
- Alternating pressure cycles (hydraulic)
- High relative speed at high pressure
- High oil temp
- High speed difference in/out
- High ICE speed
- Missalignment; runout
- High amount of pure electric driving
- High ICE revs

**Housing**
- High sum torque
- High bending torque
- Operation at bending resonance
- Boosting from low ICE-revs / impulse starts

**EOP & Hydraulics**
- High flow and pressure demand
- High oil temp
- Contamination of oil
- Varying eOP speed demands
- Long periods with full pressure demand (ICE-torque)
- High number of impulse starts

**E-drive**
- High e-drive usage @ max. e-drive torque
- High recuperation torque
- High e-drive (coil) temp
- High oil temp
- High LT-circuit temp
- As much as possible of e-drive operation
- High number of alternation drive/recuperation (pressfit)

**Main bearing**
- High ICE revs
- Check 5001
- High oil temp and high lube oil flow
- Missalignment, unbalanced components
- High ICE revs; max. allowed inbalance of input shaft

**Clutch pack wear**
- Slipping operation
- Impulse starts; poor lubrication/cooling
- Contamination of oil
- High number of impulse starts

**Clutch piston**
- Bending & wear
- Full piston travel and clutch torque
- High pressure gradients
- High accumulated piston travel
- Contamination of oil
- High number of impulse starts
- High number of C0 openings / pure electric driving

*) 1. Collection of simulation data
2. Definition of test cycle structure
3. Segmentation of simulation data
4. Load analysis Characterization of segments
5. Selection of relevant segments
6. Assembly of test cycle
Transmission - Variation of subsystem parameters (DoE)

**CAMEO - Optimization:**

- Optimization is done by an evolutionary algorithm
- Single correlations between the parameters can be shown
- Optimized micro geometry parameters regarding Transmission Error can be estimated for specific operating points.

**AVL Knowhow**

- Data Cloud
- Efficiency
- NVH
- Weight
- Transmission Error
- **Transmission Error Gear [micron]**
  - Reference: -62%
  - Var(TE): -28%
  - Var(EFF): -49%

- **Efficiency of loaded gears [%]**
  - Reference: +0.3%
  - Var(TE): +0.5%
  - Var(EFF): +0.4%
Influence of micro geometry parameters on surface vibrations

Driveline NVH-Performance
Variation of subsystem parameters (DoE)
Content

Introduction

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Validation of new design concepts – *Do the things right*

**Integrated design verification**

Summary and outlook
## Tilt Test Bed - ONE dyno configuration

<table>
<thead>
<tr>
<th><strong>1 Dyno (Tilt rig)</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Power</td>
<td>41,5 kW</td>
</tr>
<tr>
<td>Rotational Speed</td>
<td>12,000 rpm</td>
</tr>
<tr>
<td>Torque</td>
<td>100 Nm</td>
</tr>
<tr>
<td>Max. tilting speed</td>
<td>30 °/s</td>
</tr>
<tr>
<td>Max. tilting position</td>
<td>60 °</td>
</tr>
<tr>
<td>Additional facts</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Climatic chamber with temperature range -72 to +180 °C</td>
</tr>
<tr>
<td></td>
<td>• 8-Channel high resolution camera system</td>
</tr>
</tbody>
</table>
Tilt test bed - Test assembly

- Transmission – Windowed or transparent housing assembled at Tilt test bed
- Driven reverse and forward up to top speed
- Tilted to simulate acceleration, deceleration, environmental conditions,..
- Oil flow documented by footage and pictures
Tilt test bed - Action
Virtualization of Testing
Drive Testbeds
Three dyno High Load configuration

<table>
<thead>
<tr>
<th></th>
<th>3 Independent Dynos</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power</td>
<td>13,2 kW</td>
</tr>
<tr>
<td>Gear Ratio</td>
<td>1:320</td>
</tr>
<tr>
<td>Rotational Speed</td>
<td>11 rpm</td>
</tr>
<tr>
<td>Torque</td>
<td>10,000 Nm</td>
</tr>
<tr>
<td>Additional facts</td>
<td>• Flexible installation of intermediate reduction transmissions</td>
</tr>
</tbody>
</table>

Test of a differential gear / e-axle, transversal engine installation

Test of a powertrain Rear drive, longitudinal engine installation
Specialized Rig Approach – Single failure activation → Fatigue (HCF)

**HCF - Simulation**

**Damage - Calculation**

<table>
<thead>
<tr>
<th>Node</th>
<th># 14926</th>
</tr>
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<tbody>
<tr>
<td>torque</td>
<td>cycles</td>
</tr>
<tr>
<td>Overrolling_driving</td>
<td>-</td>
</tr>
<tr>
<td>-75</td>
<td>8163265</td>
</tr>
<tr>
<td>-50</td>
<td>9306122</td>
</tr>
<tr>
<td>50</td>
<td>19151020</td>
</tr>
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<td>75</td>
<td>10367347</td>
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<td>100</td>
<td>5910204</td>
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<tr>
<td>125</td>
<td>2295000</td>
</tr>
<tr>
<td>150</td>
<td>954531</td>
</tr>
<tr>
<td>175</td>
<td>209939</td>
</tr>
<tr>
<td>200</td>
<td>82449</td>
</tr>
<tr>
<td>Total sum</td>
<td>-</td>
</tr>
</tbody>
</table>
Specialized Rig Approach – Single failure activation → Fatigue (HCF)
Specialized Rig Approach – Single failure activation → Tooth contact

Similar contact pattern can be observed between simulation and testing.
Specialized Rig Approach – Single failure activation → Lifetime hybrid P2 module

**Testing Target:**
Prove of C0 clutch component life time

**Execution:**
Run 450 000 impulse starts on component rig
Specialized Rig Approach – Single failure activation → Lifetime hybrid P2 module

**Status:**
Online damage calculation from test bed data
Specialized Rig Approach – Single failure activation → Tooth contact, abuse

According to load profiles multi configuration setup
Validation & Verification
Seamless integration Testing & Simulation

- Retching of park lock system of BEV in slope situation

- Short reaction time by combine of simulation and testing strength

- Simulation input for testbed setup and test strategy → Test specification (speeds, loads)
  - Frontloading approach
  - Validation and tune of simulation by test results
  - Information gained without real HW
  - Fast results & variants conducted in virtual world
  - Maturity level checked virtual before HW
VDA – Overview Back to back testing

- Use of UuT’s
  - Customized gearboxes wheel side
  - Inverter and cables from customer
  - Condition monitoring system (additional from STD I, A, Ohm, mm/sec)

- Powerful coolant devices
  - Air: -40°C – 160°C
  - Coolant: -35°C – 120°C

- Small Footprint (1,8m x 1,5m x 1,5m)

- Scalable system, multi stage
  (room size 5m x 3m)
Back to back – Customer Application
3M Test bench E-Motor use cases – Transmission approach

<table>
<thead>
<tr>
<th></th>
<th>1 x Dyno Prime</th>
<th>2 x Dyno Train</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Power</strong></td>
<td>400 kW</td>
<td>220 kW</td>
</tr>
<tr>
<td><strong>Rotational Speed</strong></td>
<td>20,000 rpm</td>
<td>3,000 rpm</td>
</tr>
<tr>
<td><strong>Torque</strong></td>
<td>700 Nm @ 2,650rpm*</td>
<td>4,850 Nm</td>
</tr>
</tbody>
</table>

**Additional facts**

- HV-Emulator up to 500kW
- Test bed transmission speed up (ratio *2,1 and 3,6 available)
### Schematic Structure and Specification high speed transmission

**Diagram:**
- **Input E-Machine**
- **Output UuT**
- **Dimensions:**
  - **Width max.:** 300mm
  - **Center distance (input shaft - output shaft):** >290mm
  - **Width of gearbox housing:** <300mm
  - **Inner diameter output shaft:** 40mm
  - **Outer diameter output shaft:** <60mm
  - **Distance center output shaft - gearbox housing:** <65mm

<table>
<thead>
<tr>
<th>POS</th>
<th>Specification</th>
<th>Limits/Targets</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Center distance (input shaft - output shaft)</td>
<td>&gt;290mm</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Width of gearbox housing</td>
<td>&lt;300mm</td>
<td>As slim as possible</td>
</tr>
<tr>
<td>3</td>
<td>Distance center output shaft - gearbox housing</td>
<td>&lt;65mm</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Output shaft</td>
<td>Hollow shaft</td>
<td>Coaxial and axially parallel operation possible</td>
</tr>
<tr>
<td>5</td>
<td>Inner diameter output shaft</td>
<td>40mm</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Outer diameter output shaft</td>
<td>&lt;60mm</td>
<td>Directly influences limits of possible speed</td>
</tr>
</tbody>
</table>
Overview high speed transmission

Lubrication Gears

Windows CFD correlation

Lubrication Bearing (support)

Lubrication Bearing (suction)

Output shaft

Support stands bushing mounted

Housing inspection

Prime Mover
Overview high speed transmission – Different application

Off axis

Coaxial

layshaft/Coaxial
**Cycle based validation approach - Mechanical Development**

<table>
<thead>
<tr>
<th>Component</th>
<th>Test Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Needle bearings</td>
<td>open C0, closed C0 (no relative speed), high speed difference input/output, low lubrication flow, high oil temp, misalignment, runout, high amount of pure electric driving</td>
</tr>
<tr>
<td>Output shaft</td>
<td>high torque ICE+EM, misalignment, imbalance, runout, boost operation</td>
</tr>
<tr>
<td>Hydr. seal rings</td>
<td>high apply pressure, alternating pressure cycles (hydraulics), high oil temp, high speed difference in/out, high ICE speed, misalignment, runout, high amount of pure electric driving</td>
</tr>
<tr>
<td>Housing</td>
<td>high sum torque, high bending torque, operation at bending resonance, missalignment, high speed difference in/out, high ICE revs, high oil temp, high amount of pure electric driving</td>
</tr>
<tr>
<td>eOP &amp; hydraulics</td>
<td>high flow and pressure demand, high oil temp, contamination of oil, varying eOP speed demands, high number of impulse starts</td>
</tr>
<tr>
<td>e-drive</td>
<td>high e-drive usage @ max. e-drive torque, high recuperation torque, as much as possible of e-drive operation, high number of alternation drive/recuperation (pressfit)</td>
</tr>
<tr>
<td>Main bearing</td>
<td>high ICE revs (check 5001), high oil temp and high lubrication flow, misalignment, unbalanced components, high number of impulse starts</td>
</tr>
<tr>
<td>Clutch pack wear</td>
<td>slipping operation, impulse starts, poor lubrication/cooling, contamination of oil, high number of impulse starts</td>
</tr>
<tr>
<td>Clutch piston bending &amp; wear</td>
<td>full piston travel and clutch torque, high pressure gradients, high accumulated piston travel, contamination of oil, high number of impulse starts, high number of CO openings / pure electric driving</td>
</tr>
</tbody>
</table>

- Not all damage figures sufficient activated at validation phase → only 20% sufficient!
- 16 CW of powertrain testing at full assembly
Failure mode based validation approach - mechanical development

- All damage figures sufficient activated at validation phase
- Big data analytics load profile corrections on damage figure calculations → 100% controlled
- 14 CW of component testing @ #3 different rigs
Content

Introduction

Technology selection - *Do the right thing*

Validation of new design concepts – *Do the things right*

Integrated design verification

Summary and outlook
Integrated design verification - Transmission lubrication system

Lubrication system check

ROAD → Tilt Rig → Simulation

Several variants of housing, e-Motor designs, cooling layouts and baffle plates.

Proven benefits

- Concept layout validated before trying in vehicles.
- Overnight validation of new HW variants to prove simulation results.
- Multiple HW variants validated short period.
- Reduced time on costly test environments (Powertrain, climate, vehicle).
- Regular reference cycles and measurement point checks to find design improvements and reduce errors.

Reduction of development time

Reduction of cost

Increased product quality
Integrated design verification - Transmission gear train

Gear optimization

ROAD → Specialized Gear Rig → Simulation

- High model maturity in an early design phase reduces efforts in later development phases.
- Reduce validation time in case of design changes.
- Reduced cost risks in case of design changes over all development phases.
- Potential for reduced number of prototypes.
- Knowledge of influence parameters on different attributes (NVH, strength, efficiency) gained with manageable efforts.

Test beds dedicated ONLY for model validation by isolating gear pair failures

Proven benefits

- Reduction of development time
- Reduction of cost
- Increased product quality

Increased product quality

Knowledge of influence parameters on different attributes (NVH, strength, efficiency) gained with manageable efforts.
**Integrated design verification - Transmission efficiency**

### Sub-System Efficiency

**Powertrain → Transmission test bed → Simulation**

Isolated assessment of EV-Drive reducer on high-speed transmission test bed.

### Proven benefits

<table>
<thead>
<tr>
<th>Benefit</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Reduction of development time</strong></td>
<td>Reduced development risk by assessment of sub-system performance in an early stage of development.</td>
</tr>
<tr>
<td><strong>Reduction of cost</strong></td>
<td>Reduced testing costs by shifting test to on sub-system environment.</td>
</tr>
<tr>
<td><strong>Increased product quality</strong></td>
<td>Detailed knowledge of sub-system performance helps to set development targets.</td>
</tr>
</tbody>
</table>
Integrated design verification - Failure mode based durability testing

System durability testing

ROAD ➔ EV-Drive test bed ➔ Simulation

Online damage monitoring during the complete durability run

Proven benefits

- Potential reduction of duration and number of durability runs due to specific damage of components / failure modes.
- Reduced development time and number of test samples.
- Potential for decrease of design safety factors.
- Damage figures over the complete durability run helps to improve product robustness.

Reduction of development time

Reduction of cost

Increased product quality

Increased product quality
# State of the art test environments

## Test environment

<table>
<thead>
<tr>
<th>Testing attributes</th>
<th>Simulation</th>
<th>Virtual Test Bed</th>
<th>Component Test Bed</th>
<th>E-Motor Test Bed</th>
<th>EV-Drive Test Bed</th>
<th>Powertrain Test Bed</th>
<th>Road Testing</th>
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<tbody>
<tr>
<td>Performance</td>
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<td>Electric range</td>
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<td>Sound / NVH</td>
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<tr>
<td>Mechanical Durability</td>
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</tr>
<tr>
<td>Thermal durability</td>
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</tr>
</tbody>
</table>

## Price indication for environments

**LOW PRICE**

**HIGH PRICE**

---

Andreas Volk | DTV | 29 November 2018 | 50
Summary and Outlook

The deep knowledge of **sub-system influence parameters** and respective **cross influences** are mandatory to meet the **target requirements**.

By **increasing the productivity** within existing testing environments (failure mode based testing) and **shifting** to **other testing environments** (integrated design verification) **time to market requirements** can be met.
Thank You

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