Powertrain testing: Embrace the new role of testing to develop green drivetrains
On-demand Webinar
The RACE to full-electrification is on
Surviving the distance is key to success

483 companies developing electric cars & light trucks
257 companies announced autonomous drive programs
Context and trends driving innovation in today’s vehicle market

Emissions reduction & Fuel economies
- Powertrain innovation

Electrification, hybridization

Lightweight Development

Global market and customers expectations
- Local market requirements and variants
- Reliability, comfort and perceived quality
- Reduced development time and cost
Impact on product life cycle and cost
Model-Driven Design to evaluate upfront systems designs

- **Ease of change**
- **Defects identification**
- **Cost to extract defects**

100%

50%

- Model driven design
- FE driven design

Requirements | Architecture | Design, Implement & Test | Production | Delivery & Commissioning | Operation & Maintenance

Prototype driven design
Impact on product life cycle and cost
Model-Driven Design to evaluate upfront systems designs

Ease of change

Defects identification

Cost to extract defects

Model driven design

FE driven design

Prototype driven design

Requirements
Architecture
Design, Implement & Test
Production
Delivery & Commissioning
Operation & Maintenance

FE model availability
Prototype availability
Impact on product life cycle and cost
Model-Driven Design to evaluate upfront systems designs

Ease of change
Defects identification
Cost to extract defects

Model driven design
FE driven design
Prototype driven design

Requirements Architecture Design, Implement & Test Production Delivery & Commissioning Operation & Maintenance

Cost to extract defects
Defects identification
Ease of change
Adding engineering resource and depending on traditional development methods is not adequate any more.
Siemens Digital Industries Software engineering solutions
Catering to a wide range of vehicle electrification needs

- **Battery & Fuel Cell Design**
  - Chemistry | Package | Charging

- **Electrified Powertrain**
  - Motor | Generator | Inverter | Convertor

- **Electronics / Electrical Systems**
  - Architecture | EDS & Network | EMI/EMC

- **Software Controls**
  - Embedded Software | Powertrain Controls

- **Attribute Optimization**
  - Energy & Thermal Management | Acoustics & NVH
  - Durability | Aerodynamics

- **Packaging & Weight**
  - Vehicle Packaging | Light-weighting
Agenda:

Keep increasing development efficiency

Support NVH testing for electrified powertrains

Keep control on NVH for ICE
Agenda:

Keep increasing development efficiency

Support NVH testing for electrified powertrains

Keep control on NVH for ICE
How to develop powertrains faster?

Test SMARTER
- Smart interpretations
- Built-in intelligence

Test FASTER
- More efficient testing
- Automate testing
- Data Management

FRONTLOAD Testing
- Early component performance evaluation
- Test & Simulation to make early predictions
How to develop powertrains faster?
*Test Smarter*

- Pre-defined templates and displays
- Average measurements automatically
- Intelligent overview of data – Pivot Tables
- Smart Displays
- Actionable reports with active displays
- Intelligent display to evaluate large data sets
How to develop powertrains faster?
Test Faster by customizing / optimizing processes

Unification of testing Example

Old Process
1. First Prototype test to identify which subsystems cause problem
2. Instrument & test different subsystems and acquire data
3. Analysis one by one
   Total time to go through process > 2 weeks

New Process
1. Instrument complete vehicle (higher channel count)
2. Perform all test
3. **Automatic** processing for each subsystem
   Total time 3 hours

Result of unified testing:
- High reduction in total measurement time
- Always availability of ALL data
- Ideal first step towards automation of data collection too (e.g. testing without driver)
Optimization of Vehicle development cycle

The challenge

- Increasing testing effort
- Prototype availability?
- Impact of modification?
- ...

How to ensure NVH performance while keeping development time and cost under control?
Component based TPA
Value proposition

Integrated process to predict full vehicle levels in any arbitrary vehicle assembly

Realistic component target setting and down cascading

Deliver insights by frontloading the development process

Provide visibility on performance to broader enterprise

Reduced development timeline & costs
Component based TPA for component design evaluations
Enable realistic test bench based NVH target verification

OEM-Supplier cooperation

Invariant load description
AOEM

Realistic NVH design targets
Supplier

Validate performance against test bench independent targets

Variant A

Bench

Variant B

Bench A

Bench B

Validate objectively impact of design modifications or compare variants irrespective of test bench

Predict assembly NVH performance to optimize system integration

Supplier - OEM cooperation

Inertial load description
Realistic NVH design targets
How to develop powertrains faster?
Using the C-TPA methodology

Can I predict E-motor behavior from test bench?

Predict Target Response

1. Test contact loads on test bench
2. Combine Loads with Transfer to predict performance
3. High deviation between predicted and measured response

Strong coupling between source & receiver does NOT allow to exchange contact forces from bench with vehicle

Contact forces on test bench can NOT be used
How to develop powertrains faster?
Using the C-TPA methodology

Can I predict E-motor behavior from test bench?

1. Identify BLOCKED forces on test bench (invariant forces)
2. Combine Loads with Transfer to predict performance
3. Perfect match between Predicted and measured response

Blocked forces are invariant and can be used to predict the performance before integration

Concept of Component-based TPA
Enables Virtual Vehicle Assembly
Frontload Testing through combination of Test & Simulation
Model Based System Testing

System-in-the-loop testing in support of Model-Based Development
Consistent testing for shorter development cycle

✓ test component / subsystem / control unit in near-real conditions using a real-time simulation of the full system.
✓ full-system testing during all development phases: virtual (a), hybrid (b-c), physical (d)
Frontload Testing through combination of Test & Simulation

Model Based System Testing Enabling unique abilities

1. Test physical component/subsystem more realistically, by combining with virtual model

2. Test performance component/subsystem in combination with different variants in virtual model

3. Monitor any signal from within virtual model, which would be difficult to impossible to measure
Model Based System Testing
The Marriage of Test and Simulation

**Test for Simulation**
Use test data to correlate and drive simulation models for validating functional performance in a single environment
- Model validation & updating
- Model parameter identification
- Load identification
- Test data analysis expertise

Improve accuracy and ensure consistency throughout the development process

**Test with Simulation**
Use real-time simulation models to improve realism of subsystem testing
- Hardware-in-the-loop testing
- System-in-the-loop testing
- Human-in-the-loop testing

Enable earlier prototype validation and reduce integration risks

**Simulation for Test**
Use simulation models to define, improve and augment testing in a single environment
- Virtual testing
- Optimal sensor/excitation
- Virtual sensing

Provide better system insight and facilitate product performance engineering
Frontload Testing through combination of Test & Simulation

Introducing the concept of model based system testing (MBST)

✓ Sketchviewer:
  • access & process Simcenter Amesim data
  • Easy viewing & comparison data

✓ Model updating from within Simcenter Testlab to match simulation with test
Agenda:

- Keep increasing development efficiency
- Support NVH testing for electrified powertrains
- Keep control on NVH for ICE
Electric Motors Noise challenge

What is so different from ICE driven vehicles?

- Lower overall level
- Higher motor orders due to electric machine construction
- Very high frequency sounds
  - Off-zero orders
  - Related to PWM switching frequency
- Road Noise dominant due to lack of powertrain-related noise
New required functionalities in NVH testing for EV

Support to handle new sound signature

Increased need for Sound Quality
From Realistic data recording to analysis & Sound Design

Support of new sensors

Handling new important noise sources
Gear whine, Battery cooling, ...
New required functionalities in NVH testing for EV
1. Handling the different NVH signature from EV powertrains

Analysis of high frequent off-zero orders

Handling multiple RPM axis for Hybrid EV

Electric Vehicle

Hybrid Vehicle
New required functionalities in NVH testing for EV

2. Adapting to use new sensors

Measurement of Electric motor (EM) RPM:
- Usually difficult to impossible (no access)
- BUT EM has resolver sensor

- Convert electric signals from Resolver in EM RPM & angular position
- Prerequisite: measure cosine and sine coil signals from resolver

Real-time or offline post processing of signals in RPM and/or angle

Process data as with regular tacho signals
New required functionalities in NVH testing for EV

3. Sound Quality Analysis

**EV & ICE Overall noise level (dB-A)**

**Objective assessment**
Analyze your sound with measures that can be quantified

**EV & ICE Sharpness**

**EV - Prominence Ratio**

48\textsuperscript{th} Order

**EV - Sound Pressure Level**

**EV** & **ICE**

Overall noise level (dB-A)

Objective assessment
Analyze your sound with measures that can be quantified

**EV & ICE Sharpness**

**EV - Prominence Ratio**

48\textsuperscript{th} Order
New required functionalities in NVH testing for EV

3. Sound Quality Analysis

Subjective assessment
Study the *perception* of the sound
What are the positive and negative contributors to your products sound

Objective assessment
Analyze your sound with measures that can be quantified

Psychoacoustics is the science of sound perception. It studies the psychological and physiological responses associated with sound.
Control contribution of new noise sources

**Gear Whine**

Gear Whine becomes more audible:
- Reduced masking effect of EM
- Potentially gearboxes running at very high RPM (> 100 000 RPM)
- Gear whine caused on level of gear teeth (bending, clearances, eccentricity)
- Can be seen in error in transmission output RPM
- Test transmission error for different gear designs (difference in gear design)

Measurement of input and output RPM with incremental encoder
Active Sound Design
How to support key brand values with changing technology?

Need for Active Sound Design for Automotive
New challenges & opportunities require dedicated processes, skills & tools

(H) EV Exterior
Low speed pedestrian warning, AVAS system

(H) EV Interior
Great acceleration
No real sound perception

ICE
Reducing emission & weight,
Downsizing,
higher pressures
Sport >< Comfy

AV
Adaptive soundscape

Brand Values

Vehicle Sounds

Sound Quality
Delivering the right sound that supports the vehicle brand
Active Sound Design for (H)EV, ICE, AVAS

Brand Definition & Sound Branding Strategy

Active Sound Design tool
Creation, evaluation & refinement of Sound Signatures
In Office – On simulator – In vehicle

Implementation in Production vehicles
Agenda:

Keep increasing development efficiency

Support NVH testing for electrified powertrains

Keep control on NVH for ICE
How to balance NVH against performance & efficiency?

*NVH performance does not stand alone*

Implemented control strategies of ECU have direct impact on the NVH, but also overall performance & fuel efficiency!

Keep control on Powertrain NVH has become increasingly challenging

How to avoid (late) control changes impact NVH?

Solution:

Go beyond assessment of purely the powertrain NVH
How to balance NVH against performance & efficiency?

**Solution:** Combine 5 traditionally separate systems into one synchronized measurement on the powertrain test bench.

- **NVH assessment**
  - Orders, ODS, Sound Power, …

- **Torsional Vibration Assessment**
  - Torsional Resonances, Front-end Accessory drive performance, …

- **Localize Sound Source**
  - Gain insight in weak acoustic spots & components

- **Access data from ECU**
  - Access any parameter from ECU through support of CCP or XCP

- **Combustion Analysis**
  - Assess engine performance (e.g. IMEP) & efficiency
How to balance NVH against performance & efficiency?

1- Powertrain NVH Testing

Assess Operational NVH

Acceleration, Sound Pressure, Torque, RPM, Torsional vibration, Voltage, Current, Strain, CAN, Flexray, Cylinder Pressure, GPS, …

Signature Analysis
Orders, OA levels, …

Assess Sound Quality

Sound Power, Loudness, Roughness, Sharpness, …

Assess Structural behavior

… and more

Modal testing & Assess transfer functions
How to balance NVH against performance & efficiency?

2- Link ECU information with NVH & performance

| Amount of information accessible | Low | High |

### Diagnostics protocol
- OBD-II (even used for car maintenance)
- Gives access to limited information such as RPM, vehicle speed
- NO dbc file required

### CAN traffic protocol
- Requires dbc file to interpret information
- Also support for FlexRay traffic (fibex file)
- Support of CAN-FD

### Calibration protocol (CCP/XCP)
- Direct Access to memory of ECU
- Requires A2L file
- Requires third party partner

For instance IPEtronik Fleetlog2 configured as gateway

Only for own cars & typically less experience in NVH teams
How to balance NVH against performance & efficiency?

3- Assess Torsional Vibrations: From prediction to visualization

- Use simulation models to predict torsional vibration
- Easy to modify to minimize the effect

**Torsional Vibration Testing**

- Optical probes, incremental encoder, magnetic pick-ups, torsional laser, etc.
- Measurement:
  - High number of pulse/rev
  - Torsional vibration orders
  - Animation of results
How to balance NVH against performance & efficiency?
4- Combustion Analysis to assess combustion performance

Support of required sensors

Pressure sensor
- Direct connection of pressure sensor

Angular Position
- Crank shaft Angular position
  - Magnetic Pick-up
  - Optical Coders

Assessment of many combustion metrics

Important metrics for Combustion Analysis
- PV-diagram
- Mean Effective Pressure:
  - IMEP/NMEP/PMEP
  - BMEP/Mechanical Efficiency
- Peak Pressure, Pressure Rise Rate, Burn Rate

Support correction for temperature drift (Pegging)
Zero Angle Reference TDC
Automatically or manually
How to balance NVH against performance & efficiency?

5- Array of microphones for Sound Source Localization

Use of array of microphones

Scalable digital array

Scalable in size
- 45 mics
- 81 mics
- 117 mics

Easy to include in powertrain measurement chain

Correlation with NVH measurements

Always be ready to analyze conditions using the arrays of interest

Wide frequency

Sound power

Add-ons for:
- Focus on orders or moment within combustion cycle
- Separate combustion & mechanical noise
Value of measuring all 5 systems together
*Balancing NVH against other attributes*

**Example 2**
Assess Engine map for not only NVH but also Performance metrics, torsional ...

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1. Measure NVH
2. Assess IMEP & Powertrain Efficiency
3. Assess Torsional Vibration orders
4. Assess ECU parameters
5. Localize Sound Sources for certain conditions
## Powertrain NVH Testing

### Key take-aways

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<thead>
<tr>
<th>Increasing development efficiency</th>
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<tr>
<td>✓ Increase NVH testing efficiency</td>
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### Support NVH testing for electrified powertrains

<table>
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<th>✓ Cover needs for electrified powertrains</th>
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<td>✓ Support for more important sources</td>
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### Keep control on NVH for ICE

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<th>✓ Go beyond pure NVH testing</th>
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<td>✓ Combining separate measurement systems into one integrated test</td>
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Thank You