Address NVH integration issues from concept to validation through model-based development (MBD)

Wednesday January 23, 2019
Vehicle NVH Innovation Area

Challenges

Vehicle Electrification
200+ (H)EV models. Increased engineering complexity

“OEMs and suppliers understand that NVH features can become the main differentiation factor among automotive companies.”

Visiongain, NVH market report

Analyze electrical and mechanical design
Vehicle NVH Innovation Area
Challenges

Driveline integration
Low-frequency torsional vibrations are amplified in the driveline

"Predicting systems behavior upfront significantly reduces the workload and allows us to focus efforts and resources on other priorities, such as brand image and value”

S. Watanabe
Powertrain NVH, Honda R&D

Ensure smooth vehicle integration

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Vehicle NVH Innovation Area
Challenges

Balancing performances
Conflicting performance characteristics (NVH, energy management, drivability)

“Balancing CO2 reduction requirements and increasing customer expectations constrains the feasible solutions zone, requiring an integrated approach”
Tom McCarthy
Chief engineer PT Research & Advanced Engineering, Ford

Balance NVH with other attributes
Current vehicle NVH engineering process

Challenges

Target setting and benchmarking
- Many new vehicle architectures and variants
- New fuel economy & safety regulations

Test-based validation
- Issues occur in prototype stage
- Limited design space for solutions
- Long time to solve

NVH CAE engineering
- Starts late in the process
- Needs detailed geometry
- Limited space for design changes
Addressing these challenges requires an integrated approach.

What if we could add Model-Based Development to the process?
From CAD-centric to System-centric thinking

**Target setting and benchmarking**
- Shortens testing phase
- Multi-attribute target setting and evaluation
- Cascade system targets down to components

**Validation**
- Get insight in rotational dynamics
- Reduce prototype troubleshooting time

**Virtual Verification**
- Verify component performance at system level before prototype is available

**NVH System Engineering**
- Frontload design choices
- Feasible even without detailed geometry
From CAD-centric to System-centric thinking

**Target setting and benchmarking**
- shortens testing phase
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**Virtual Verification**
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NVH System Engineering
Process deployment for NVH Investigation

Torsional driveline model
Coupled with suspension and vehicle model

Component – system tests
Vehicle tests

Diagnose
Insights

Update & Validate
Complement

Sca
lable model complexity
f(accuracy, information)

Sensitivity studies
Design exploration
Change impact

Model provides insight in rotational dynamics
& coupling driveline and suspension dynamics

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NVH System Engineering
How to incorporate 3D dynamics in system simulation

Suspension and Tire

Relevant tire and suspension dynamics needs to be included for booming evaluation up to 80Hz

Wheel Driving Point FRF X

For-aft mode ~20Hz
Rotational mode ~60Hz

2D elements available in system simulation to include suspension dynamics

Detailed tire model for NVH
NVH System Engineering
Low-Frequency Booming Noise

Solution
- MBD driveline coupled with Test or FE transfer function
- Closes the loop from engine inputs to interior noise
- Enables tuning/optimization of driveline parameters to reduce booming

Shift Shock
Clunk
Judder
Booming
Squeal
Engine Re-start
1D Rattle
2D Rattle
Switching & slotting effects

model input: Combustion pressure or engine control signals
Interface forces calculated from full vehicle model
Target response: model loads x measured FRF
NVH investigation and improvement of a rear wheel drive vehicle
Using a model-based approach combining test and simulation methods

Model-based approach by combining test and simulation

- Reverse engineer competitor vehicle to understand driveline contributions for lock-up booming noise and vibrations
- Static and dynamic characterization of components based on full vehicle measurements

Reverse engineering of CPVA

- Using testing methods for gaining insight and obtaining parameters for modeling
- Using simulation to validate and update the sub-systems to create a full vehicle model

Full vehicle modeling

“The Simcenter Engineering team smartly combined operational measurements to gain insights into the vehicle behavior, noise sources and noise transfer paths, with simulation models to build a full vehicle model. We were able to evaluate the performance of the CPVA and reduce lock-up booming noise.”
Automobili Lamborghini
Creating a new driveline concept design using Simcenter Amesim

- Designed the torsional vibration characteristic of the Aventador LP700-4 driveline
- Supported torsional vibro-acoustic driveline optimization

Designing the Aventador LP700-4 torsional vibro-acoustic driveline

- Powertrain and gearbox noise optimization
- Torsional behavior of the driveline

- Model easily complex dynamic systems using prepackaged components
- Generate models in function of the phenomena the user intends to investigate

“The true power of Simcenter Amesim is demonstrated by how easy it is to evaluate different driving conditions, software or hardware changes and even different configurations”.

Ing. Claudio Manzali, R&D
NVH System Engineering
Engine re-start shock for PHEV

Solution
- MBD representation of driveline and vehicle
- Closes loop from engine inputs to chassis response
- Enables optimization of active control strategy

Shift Shock
Clunk
Judder
Booming
Squeal
Engine Re-start
1D Rattle
2D Rattle
Switching & slotting effects

...
Honda Motor Company
Resolve hybrid engine restart vibrations

Reduce vibrations at restart of hybrid engines while balancing fuel economy and performance

Test methods such as transfer path analysis, impact testing, modal analysis, and more

Results of in-cylinder pressure at engine restart using 1D prediction model

- Solve hybrid engine restart vibrations
- Take into account the entire powertrain restart process and allow for varying in-cylinder pressure
- Reduce time to market

“Thanks to the Simcenter engineering expertise, we predict systems behavior upfront. The workload afterwards is significantly reduced, which allows us to focus our efforts and resources on other priorities, such as brand image and value.”

Satoshi Watanabe, Model-Based Design for Powertrain NVH
# NVH System Engineering

## Gear Rattle

### Rattle assessment

- Low Frequency excitation
- Torque zero passing in idle gears → impact

### Rattle propagation

- Broadband noise
- Propagation through transmission casing and mounts

### Rattle-free design

Focus on reducing losses, makes rattle-free design harder

- Bearing losses
- Oil churning losses in Idler gears

### Rattle metrics

- Difficult to objectively quantify rattle

<table>
<thead>
<tr>
<th>Bearing losses</th>
<th>Oil churning losses in Idler gears</th>
<th>Rattle metrics</th>
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</thead>
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<tr>
<td><img src="image1.png" alt="Bearing losses" /></td>
<td><img src="image2.png" alt="Oil churning losses" /></td>
<td><img src="image3.png" alt="Rattle metrics" /></td>
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### NVH System Engineering

#### Gear Rattle

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<th>Shift Shock</th>
<th>Rattle assessment</th>
<th>Rattle propagation</th>
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<tr>
<td>Clunk</td>
<td>- System simulation driveline modeling</td>
<td>- structural FE models and acoustic</td>
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<td>Judder</td>
<td>- Extract gear contact forces</td>
<td>models</td>
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<tr>
<td>Booming</td>
<td>- Detailed loss models in function of</td>
<td>- Coupling with gear forces for target</td>
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<td>Squeal</td>
<td>physical parameters</td>
<td>prediction</td>
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<td>Engine</td>
<td>- Virtual troubleshooting</td>
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<td>Re-start</td>
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<td>1D Rattle</td>
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<td>2D Rattle</td>
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<td>Switching &amp;</td>
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<td>slotting</td>
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<td>effects</td>
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<tr>
<td>Drivability</td>
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</tbody>
</table>

#### Rattle-free design

- Multi-phase CFD analysis
- Coupling with lubrication modeling for boundary condition
- Balancing losses - rattle

#### Rattle metrics

- Subjective-objective correlation
- Sound quality analysis
- Metric development

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**Diagram:**

- Gear train
- Bearing
- Casing vibration
- Air
- Airborne noise
From CAD-centric to System-centric thinking

**Target setting and benchmarking**
- Shortens testing phase
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**NVH System Engineering**
- Frontload design choices
- Feasible even without detailed geometry
Virtual Validation
System-in-the-loop testing

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

- Virtual testing
- Conventional bench testing
- Conventional bench testing
- Field testing

- Model Based System Testing
- System-in-the-loop
- Model Validation

- 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)
Virtual Validation
Hardware-in-the-loop testing

HiL for HEV control pre-calibration for MAB

Closed-Loop HIL

- Real-Time Simulator – dSPACE
- Amesim

Validation – NVH
- Tip-in Tip-Out – EV Mode
- E-Motor speed [rpm]
- Vehicle speed [kph]
- Vehicle acc. [m/s²]

CUSTOMER REFERENCES

Published Paper
Development of a Hardware In the Loop Setup with High Fidelity Vehicle Model for Multi Attribute Analysis
Jae-Sung Bang, Tae-Soo Kim, Sook Hyun Choi
Eco-Vehicle Control System Development Team
R&D Division, Hyundai Motor Group
Seoul, South Korea
aemosim@hyundai.com

Raphael Rhoet-Vanney, Harikrishnan Rajendran
Pilhar
MBSE Engineering Services
Siemens PLM
Exton, USA

Validation – Energy efficiency

NEDC
FTP
HWY

The errors between the test data and the simulation data is less than 2%!
From CAD-centric to System-centric thinking

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Validation
Enhance test-based troubleshooting

System simulation model of vehicle → Next Generation Design

Operational Test Campaign → Root-cause Analysis → Updating

Combine **test data** analysis and **system simulation** to:

- Tackle the issue in the driveline
- Reuse in next generation vehicle design

**Test, simulation, CAN/ECU overlaid for root cause analysis**

**Additional insight by using simulation model**
Validation
Synchronizer gear rattle at low frequencies

Solution
- Detailed MBD model of the transmission
- Combined test and system simulation troubleshooting
- Unexpected NVH issue can be included in next generation design verification
From CAD-centric to System-centric thinking

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Target Setting and Benchmarking
Why Multi-Attribute Balancing

Challenge: balance conflicting attributes → modifying the vehicle in refinement stage is too costly

- Better energy efficiency is required → Some measures often degrade NVH performances (downsizing engine, idling stop, lower speed at Lock Up, weight saving, ...)

Solution:
- Deploy multi-attribute testing campaign for target setting
- Develop unified modeling approach for performance balancing at early stage
Target Setting and Benchmarking
Multi-attribute testing

To synergize
Unified setup

<table>
<thead>
<tr>
<th>Feature</th>
<th>Durability</th>
<th>Handling</th>
<th>Comfort</th>
<th>Drive-ability</th>
<th>LF NVH</th>
<th>Asset turnover ratio [y coverage / x use]</th>
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<tr>
<td>Spindle forces</td>
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<td>YES</td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

To automate
Scheduling & Monitoring

GPS Based acquisition

Customer statement “Our new design verification process is now 5 times shorter and the processing of data has gone from 2 weeks to 3 hours”
Target Setting and Benchmarking
Unified modelling approach

Scalability concept

Booming

Unified parametrisation

Cross-department data gathering

Change model complexity depending on attributes

Ensure parameters consistency between models

Model parameters
Simulation specific parameters
Tip-In model
Start model
VEM model

Fuel consumption

Vehicle dynamics

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Mitsubishi Motor Company
Technology development to allow multi-attribute evaluation

Multi-attribute balancing of NVH, drivability and energy management

- Satisfy multiple performance at the early stages of vehicle development
- Evaluate design parameters and control settings on different attributes
- Reduce risk of issues during validation

"Simcenter Engineering services helped us to apply performance balancing at the early stages of development, contributing to prevent development reworking."

Paper at SAE
Conclusions
Added value of Model-Based Development for NVH

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Aisin AW
Strengthening its position as technology partner

- Gained 50 percent time reduction when troubleshooting a new NVH issue
- Significantly reduced overall development time
- Recognized as technology partner of automotive OEMs, resulting in competitive advantage

Reducing booming, judder and gear noise

- Deploy a full vehicle model based approach for the prediction and elimination of clutch judder
- Employ full vehicle modeling approach combining test, 3D and 1D simulation methodologies

“Many NVH techniques we learned from Simcenter Engineering are now part of our standard development process, such as transfer path analysis.”

Hiroki Tsuji, Group Manager, Core Component Engineering Department
Thank you! Want to know more?

Read more

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Watch videos

Contact the expert