Analysis of Structure Born Noise and Noise Transfer Path in Modern Powertrains with MBD Simulation

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Agenda

› Integration of simulation and testing in acoustical engineering

› Design workflow with MBD systems

› Comparison of measurement and simulation

› Example 1: influence of different excitations

› Example 2: effects of structure variants

› Example 3+4: analysis of system behaviour

› Summary
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Integration of simulation and testing

Powertrain NVH simulation and testing is fully integrated in the acoustic department of vehicle engineering.
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› Summary
NVH-Design Workflow with MBD systems

- MBD = Multi-Body Dynamics

- Workflow which is in use for a variety of ongoing projects

- Electrified drivetrains

- Conventional drivetrains
NVH-Design Workflow with MBD systems

MBD = Multi-Body Dynamics

an important core process of acoustical engineering
NVH-Design Workflow with MBD systems
NVH-Design Workflow with MBD systems

- engine
- gearbox
- crankshaft
- ...

Detailed FE-models
NVH-Design Workflow with MBD systems

- Detailed FE-models
  - engine
  - gearbox
  - crankshaft
  - ...

- Interactions / Internal excitations
  - nonlinear couplings
  - bearings
  - springs / dampers
  - gear-couplings
  - ...

- Engine components

- Gearbox components

- Crankshaft components
NVH-Design Workflow with MBD systems

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Interactions / Internal excitations
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- ...

External excitation
- thermodynamic pressure
- forces, moments
- ...

Pressure, forces and moments

Indicator diagrams
NVH-Design Workflow with MBD systems

Nonlinear MBD analysis
› different load conditions
› complete engine maps
› run-up / stationary / instationary
› ...

Detailed FE-models
› engine
› gearbox
› crankshaft
› ...

Interactions / Internal excitations
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› ...

External excitation
› thermodynamic pressure
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› ...

AVL EXCITE™
Multi-Body Dynamics Simulation Software
NVH-Design Workflow with MBD systems

Nonlinear MBD analysis
- different load conditions
- complete engine maps
- run-up / stationary / instationary
- ...

Postprocessing step
- signal conversion to HEAD hdf-files
- postprocessing in HEAD/Artemis
- batch scripts
- ...

Detailed FE-models
- engine
- gearbox
- crankshaft
- ...

Interactions / Internal excitations
- nonlinear couplings
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External excitation
- thermodynamic pressure
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Signal conversion to HEAD hdf-files
Postprocessing in HEAD/Artemis
Batch scripts
NVH-Design Workflow with MBD systems

Evaluation and analysis
- campbell diagrams
- modal participations
- structure born noise
- surface velocities
- operational mode
- ...

Postprocessing step
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Nonlinear MBD analysis
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External excitation
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Simulation HL3 X
500Hz Oktave
NVH-Design Workflow with MBD systems

» Optimization of structure and excitation

Evaluation and analysis
› campbell diagrams
› modal participations
› structure born noise
› surface velocities
› operational mode
› ...

Postprocessing step
› signal conversion to HEAD hdf-files
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Detailed FE-models
› engine
› gearbox
› crankshaft
› ...

Interactions / Internal excitations
› nonlinear couplings
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› gear-couplings
› ...

External excitation
› thermodynamic pressure
› forces, moments

Nonlinear MBD analysis
› different load conditions

» Optimization of NVH behaviour + deepening the system knowledge
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Comparision of measurement and simulation

**measurement**

<table>
<thead>
<tr>
<th>f/Hz</th>
<th>measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1500</td>
<td>3500 n/rpm 6000</td>
</tr>
</tbody>
</table>

**simulation**

<table>
<thead>
<tr>
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<th>simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1500</td>
<td>3500 n/rpm 6000</td>
</tr>
</tbody>
</table>

<30 dB>
Comparision of measurement and simulation

In general: good correlation to measurements, some details not yet covered in simulation
Comparision of measurement and simulation

measurement

simulation

acc@MP2 in X-dir.

1kHz Octave @MP2 in X-dir.

<30 dB>
Comparision of measurement and simulation

Good correlation to measurements, some details not covered in simulation e.g. excitation of beltdrive
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Example 1: different thermodynamics identical engine hardware

Simulation engine#1

Simulation engine#2

structure born noise
500Hz Octave @ MP1

Full load condition
- Engine 1 higher acoustic level

Part load condition
- Engine 2 higher acoustic level
Example 1: different thermodynamics part load condition @150Nm

In part load run-up the difference between the engines is significant
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Example 2: influence of crankshaft stiffness

Significant effect of the crankshaft stiffness on structural borne noise at interface to the vehicle
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Example 3: analysis of the system resonance at MP2

Simulation

acc@MP2

<30 dB>
Example 3: analysis of the system resonance at MP2

Analyzing system behaviour:
› Modal data recovery from run-up
› FFT of modal scale factors (MSF)
› Freq-Time filter of MSF
› Complex multiplication of filtered MSF with Eigenvectors
› ∑ MFS x EV = operational mode at specified frequency / time band

» System analysis by freq/time specific operational modes
Example 3: analysis of the system resonance at MP2

Operational mode @900Hz  @5200rpm
Example 3: analysis of the system resonance at MP2

Operational mode @900Hz @5200rpm: influenced by flywheel axial resonance
Example 4: analysis of the system

2.5\textsuperscript{th} engine order

- Simulation
- Measurement

2.5th engine order

Acc@MP1

<30 dB>
Example 4: analysis of the system
2.5\textsuperscript{th} engine order

simulation

acc@MP1

2.5th engine order

simulation
measurement

MP1

<30 dB>
Example 4: analysis of the system 2.5\textsuperscript{th} engine order

Operational mode @2.5\textsuperscript{th} ord. @4700rpm: characterized by global bending modes
Example 4: analysis of the system 2.5\textsuperscript{th} engine order

Operational mode @2.5\textsuperscript{th} ord. @4700rpm: influenced by flywheel tumble motion
Summary

› Multi-Body Dynamic simulation in modern drivetrains

› show a good correlation to measurements,
  for further improvement additional excitation mechanisms will be included

› is an efficient tool to analyze and evaluate different design parameters

› can predict system behaviour due to design changes (early project phase)

› can visualize system behaviour, often not available in test environment

› enables a deep understanding of system behaviour

› will be further developed e.g. to analyse time structured signals (roughness), to include energetic quantities and detailed transfer path analysis features

» MBD simulation is an efficient tool for NVH optimization in ALL design stages
Thank you!
Thank you!