Multi-Body Simulation of Powertrain Acoustics in the Full Vehicle Development

SIMPACK User Meeting 2011

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Salzburg, 19.05.2011
Powertrain Acoustics in the Full Vehicle Development

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Aspects of Powertrain Acoustic Design

- Model Validation
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- Contribution Analyses

Summary / Further Steps

Comments / Suggestions
**Vibration Phenomenon**
- Accelerating
- Booming Noise Inside Cabin
- Frequency Range < 70 Hz
- Increased because of Rear Axle Vibrations

**Physical Mechanism**
- Engine Excitation
- Cutting Forces in Rear Axle Carrier Mounts
- System Boundary of MBS Model

**Multi-Body Simulation of Powertrain Acoustics**

**FEM: Vibro-Acoustic Transfer Function**

**Problem**
# Multi-Body Simulation of Powertrain Acoustics

## Approach

<table>
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<tr>
<th>„Substitution Test“</th>
<th>Test</th>
<th>MBS-Simulation</th>
</tr>
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<tr>
<td>Measured/Calculated Variables</td>
<td>Accelerations, Shaft Torques, Angular Velocities</td>
<td>Cutting Forces in Rear Axle Carrier (HAT) Mounts</td>
</tr>
<tr>
<td>Dimensioning Parameter</td>
<td>Interior Noise Level</td>
<td>Cutting Forces in Rear Axle Carrier (HAT) Mounts</td>
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</tbody>
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The approach involves comparing measured/calculated variables with results from MBS-simulation. The process includes dimensioning, verification, and simulation components.
Multi-Body Simulation of Powertrain Acoustics

Model (approx. 150 dof)

- Subsystems:
  - Powertrain Model (AS)
  - Rear Axle Model (HA)
  - Engine/Roller Excitation
- Rigid Body (Base Version)
- Tire Model (‘Pacejka Magic Formula’)
- Friction in Powertrain and Rear Axle
- Nonlinear Characteristics
- Amplitude-Frequency Rubber Characteristic

Load Case

- Full Throttle Acceleration in a Fixed Gear
- Rheonomic Roller Speed
- Excitation Torque on Crank Shaft
  - Constant: Nominal Torque
  - Alternating: Inertia and Induced Torques
- Simulation: Time Domain
- Analyses: Frequency Domain
Aspects of Powertrain Acoustic Design
Model Validation – Intention, Approach

MBS-Model Developing in Terms of Powertrain and Rear Axle Vibrations

Preceeding Model → Current Production Vehicle
Phenomenon → Torsional Excitation Transferred by Rear Axle into Car Body
Model Topology → Degrees of Freedom, Nonlinearities
Model Update → Parameters, Database
Relative Prediction → Validated MBS-Model

„Iterative“

Validated MBS-Model
➢ Model Based Vibration Analyses
  („Understanding of the dominant vibration phenomenon“)

➢ Development on the Basis of Cutting Forces
  („Total vertical force of the rear axle carrier mounts“)
Aspects of Powertrain Acoustic Design
Model Validation – Results

Dominant Vibration Phenomenon

- total vertical force - rear axle carrier
  - Rear Axle (HA) Pitching
  - Final Drive (HAG) Rolling

Simulation vs. Measurement

- vertical acceleration - rear axle carrier (pos.: rear right)

Coupled Eigenmode 1

Coupled Eigenmode 2
Aspects of Powertrain Acoustic Design

Sensitivity Analyses

Parameter Sensitivity

- Stiffness Distribution in HAG or HAT Mounts
- Rubber Characteristics
  (Amplitude, Frequency and Damping)
- Lengthwise Support of the HAT Mounts
  (see Example)

Topology Options

- Positioning/Number of the HAG Mounts
- Comparison of Different Rear Axle Concepts
  (see Example)
Aspects of Powertrain Acoustic Design
Basic Dimensioning – Approach, Static

Approach Sequence

Boundary Conditions → Static → Dynamic → Design Proposal

Axle Concept, Mount Position, Traction and Powertrain Configuration

Support of the Nominal Torque, Maximum Allowable Displacements, Drive Shaft Working Angle

Stiffness Distribution, Rubber Characteristics, Dynamic Optimization

Basic Static Dimensioning

![Diagram of a car suspension system showing the relationship between drive shaft working angle (x-z plane), max. traction, and rear axle driving torque (Nm).](image)
Optimal Pitch Stiffness Ratio HAT/HAG Mounts

\[
\frac{1}{CR_{\text{total}}} = \frac{1}{CR_{\text{HAT}}} + \frac{1}{CR_{\text{HAG}}}
\]

\[
\text{pitch stiffness ratio} = \frac{CR_{\text{HAG}}}{CR_{\text{HAT}}}
\]

Detailed Dimensioning
- Rubber Characteristics
- Stiffness of the Secondary Mount Directions (lateral, longitudinal)
Aspects of Powertrain Acoustic Design
Optimization

Absorbance and Damping Measures
➢ Hydraulically Damped HAG Mounts ①
➢ Vibration Absorber at HAT or HAG ②
➢ Torsional Dynamic Absorber (Powertrain) ③

Example: Torsional Dynamic Vibration Absorber
➢ Influence of Tuning Frequency

- Hydrodynamic HAG mount
- Stiffness [N/mm]
  - 600
  - 900
  - 1200
  - 1500
  - 1800
  - 2100
  - 2400

- Loss angle [deg]
  - 30°
  - 60°
  - 90°
  - 120°

- Total vertical force - rear axle carrier

- Torsional dynamic vibration absorber
Aspects of Powertrain Acoustic Design

Contribution Analyses

SIMPACK TMB
Linear System Matrices
(A, B, C, D)

State Space Model
\[
\begin{align*}
\frac{dx}{dt} &= Ax + Bu \\
y &= Cx + Du
\end{align*}
\]
Transfer Function \( H \)

Hybrid MBS Model
Frequency Sweep in Time Domain

Frequency Range
Coupling forces on TMB \( f \)

\[
Y = H \times f
\]

\[
\begin{bmatrix}
Y_{FSS} \\
Y_{Fedo}
\end{bmatrix} = \begin{bmatrix}
H_{11} & H_{12} & \cdots & F_{XSL} \\
H_{21} & H_{22} & \cdots & F_{YSL}
\end{bmatrix}
\]

\[
Y_{FSS} = H_{11}F_{XSL} + H_{12}F_{YSL} + \ldots
\]

contribution of the comfort level (single rpm)

entire comfort level

single contribution

entire comfort level

Vij (residual: e.g. engine mounts)
Vij (HAT mount vertical direction - front left)
Vij (HAT mount vertical direction - front right)
Vij (HAT mount vertical direction - rear left)
Vij (HAT mount vertical direction - rear right)
SIMPACK has become an important tool within the concept design of powertrain acoustics in the full vehicle development at BMW.

The ever shortening development times and the vast scale of powertrain and car body variants together demand a technically advanced dimensioning and verification process using virtual prototyping.

SIMPACK, and the modular approach used at BMW, have made it possible to implement this complicated dimensioning process.

The entire vehicle virtual dimensioning process and validation methods, with the challenges associated with vehicle down-sizing and down-speeding, are continually being developed with the help of SIMPACK.
Comments / Suggestions

- Visualization of operational shapes from stationary vibrations.

- Data type 'String' should be usable as parameters.
  
  e.g. string.str ($\_9904\_PA\_DATENFILE)= M:\Projekte\m3D_dummy.dat'

- Visualisation of the principle axis of the body inertia tensors based on the model parameters.