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

SIMPACK User Meeting 2011

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BMW Group

Powertrain Acoustics in the Full Vehicle Development
Contens

Multi-Body Simulation of Powertrain Acoustics

- Problem
- Approach
- MBS-Model

Aspects of Powertrain Acoustic Design

- Model Validation
- Sensitivity Analyses
- Basic Dimensioning
- Optimization
- Contribution Analyses

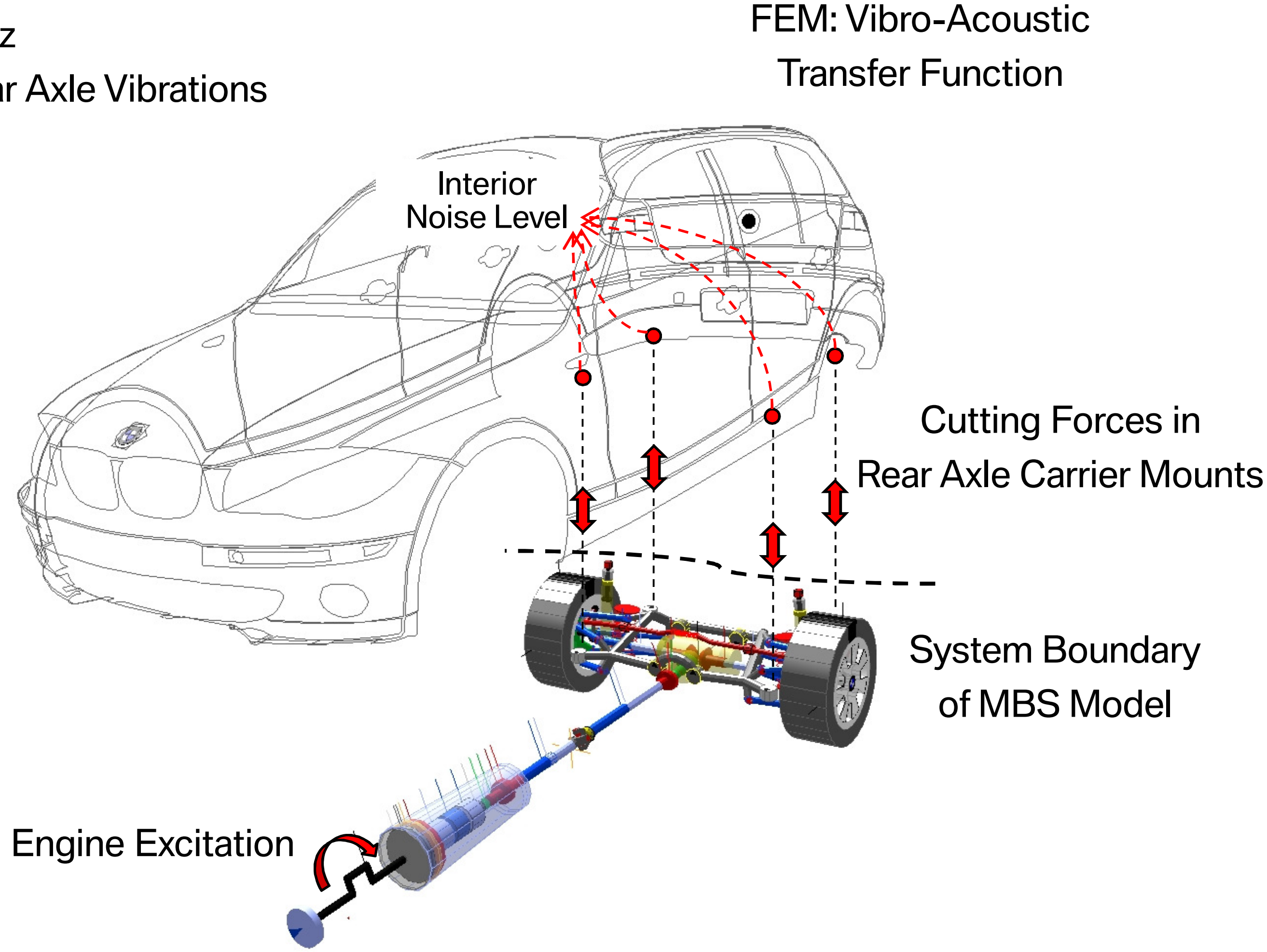
Summary / Further Steps

Comments / Suggestions

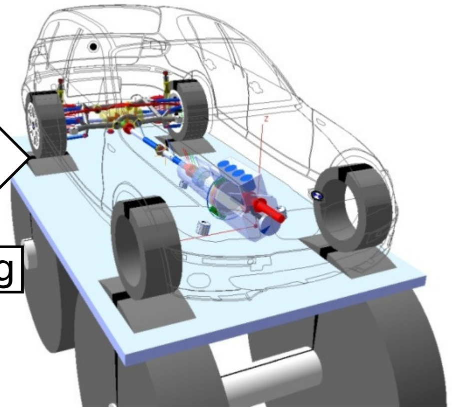
Multi-Body Simulation of Powertrain Acoustics
Problem

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

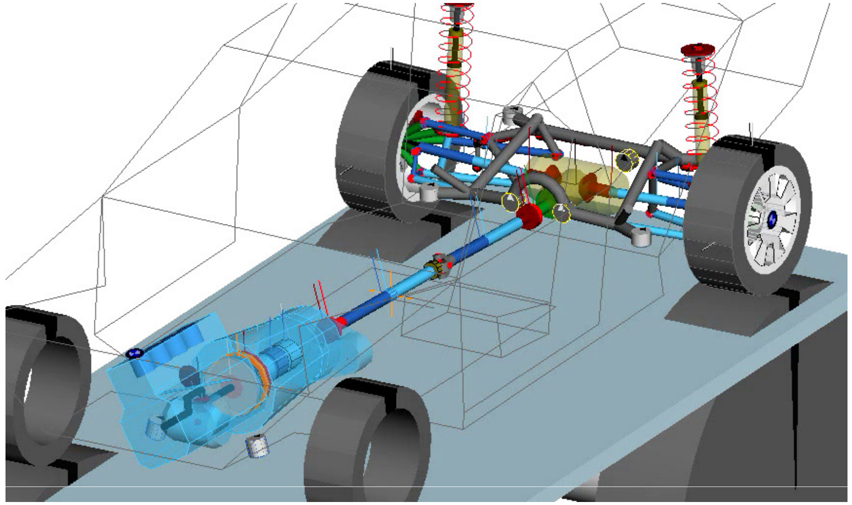
Physical Mechanism



Multi-Body Simulation of Powertrain Acoustics
Approach

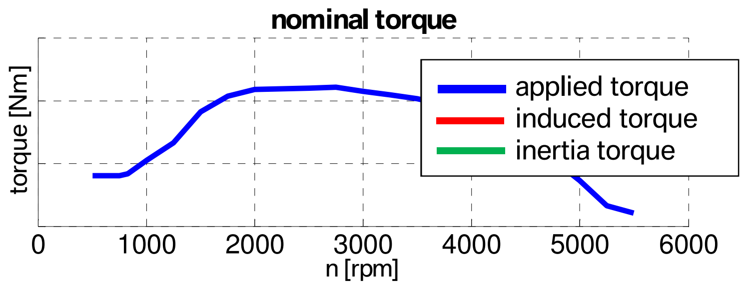
„Substitution Test“	Test	MBS-Simulation
	 Verification → ← Dimensioning	
Measured/ Calculated Variables	Accelerations, Shaft Torques, Angular Velocities	Accelerations, Shaft Torques, Angular Velocities Cutting Forces in Rear Axle Carrier (HAT) Mounts
Dimensioning Parameter	Interior Noise Level	Cutting Forces in Rear Axle Carrier (HAT) Mounts

Multi-Body Simulation of Powertrain Acoustics
MBS-Model



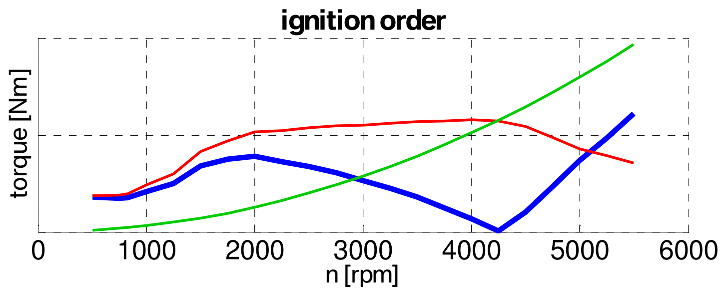
Model (approx. 150 dof)

- 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

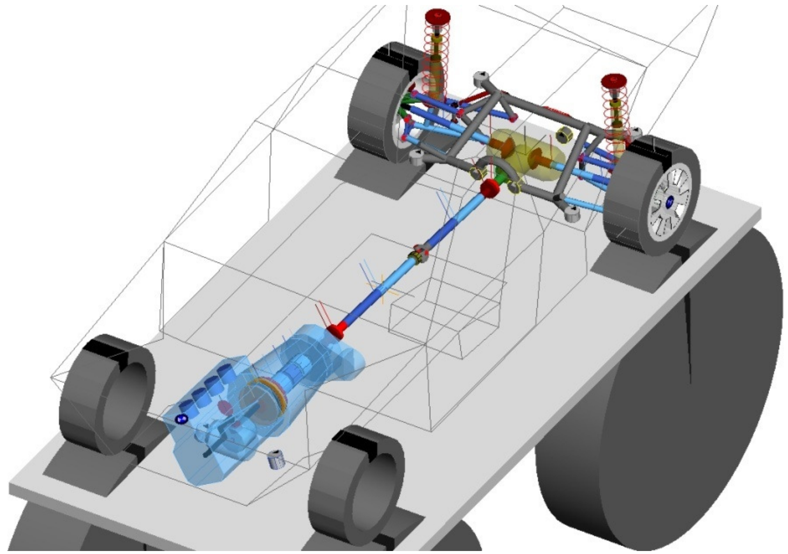
Preceeding Model	Current Production Vehicle
Phenomenon	Torsional Excitation Transfered by Rear Axle into Car Body
Model Topology	Degrees of Freedom, Nonlinearities
Model Update	Parameters, Database
Relative Prediction	Validated MBS-Model

„Iterative“

Validated MBS-Model

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

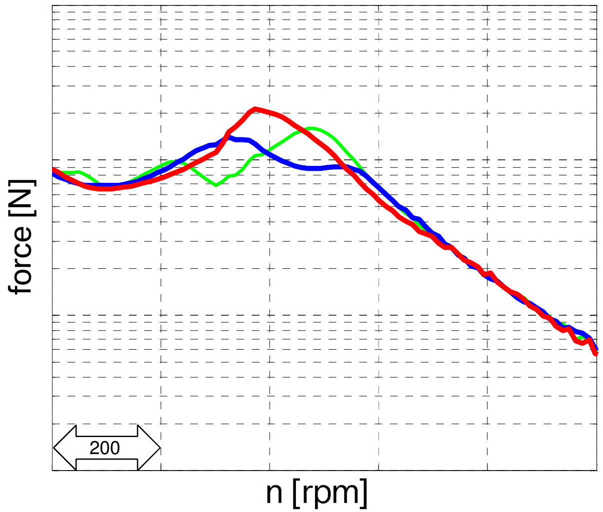
- Development on the Basis of Cutting Forces
  („Total vertical force of the rear axle carrier mounts“)



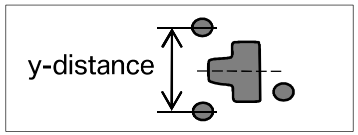
Aspects of Powertrain Acoustic Design
Model Validation – Results

Dominant Vibration Phenomenon

total vertikal force - rear axle carrier

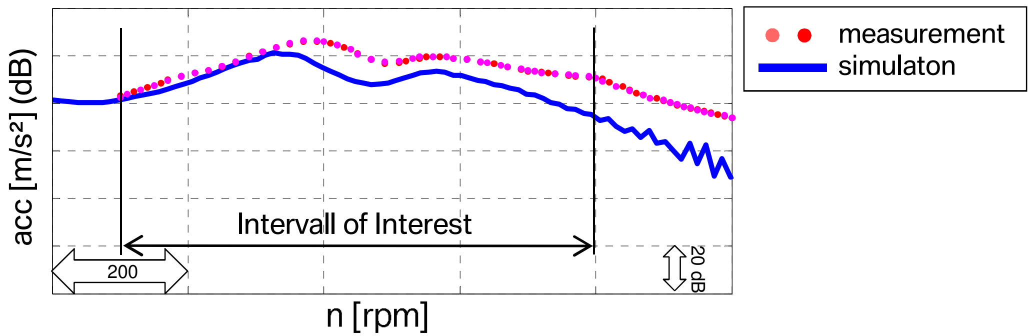


- Rear Axle (HA) Pitching
- Final Drive (HAG) Rolling

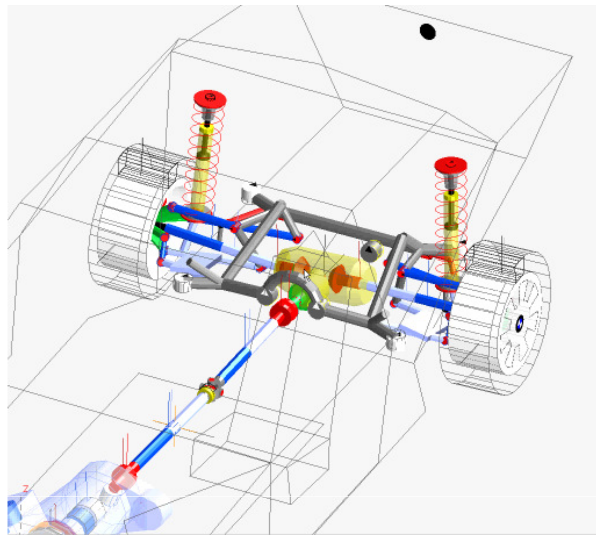


Simulation vs. Measurement

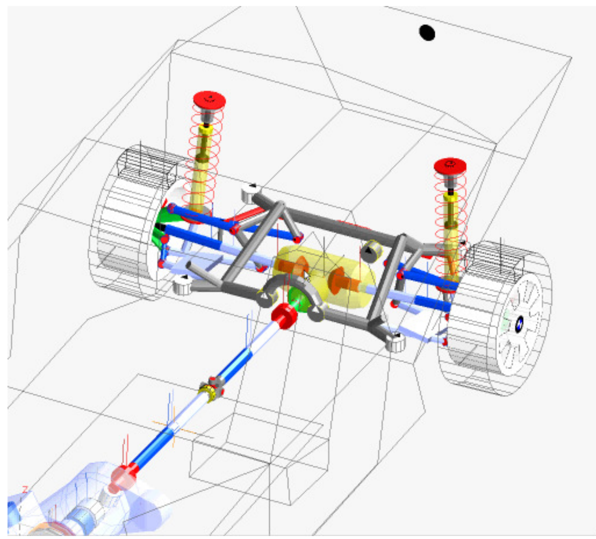
vertikal acceleration - rear axle carrier (pos.: rear right)



Coupled Eigenmode 1



Coupled Eigenmode 2



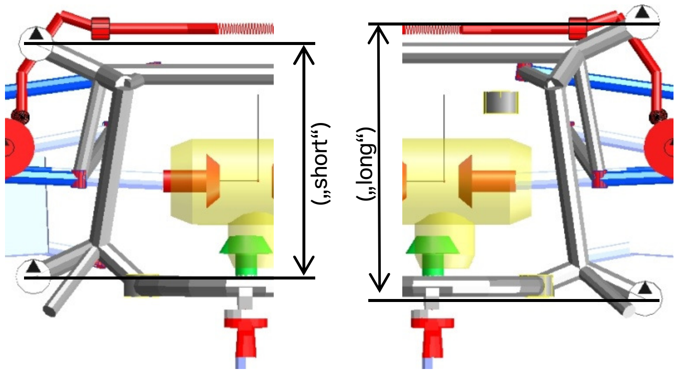
Aspects of Powertrain Acoustic Design
Sensitivity Analyses

Parameter Sensitivity

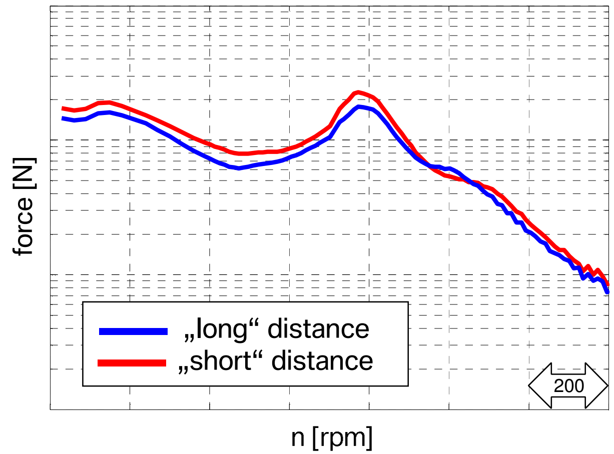
- Stiffness Distribution in HAG or HAT Mounts
- Rubber Chracteristics (Amplitude, Frequency and Damping)
- Lengthwise Support of the HAT Mounts (see Example)

Topology Options

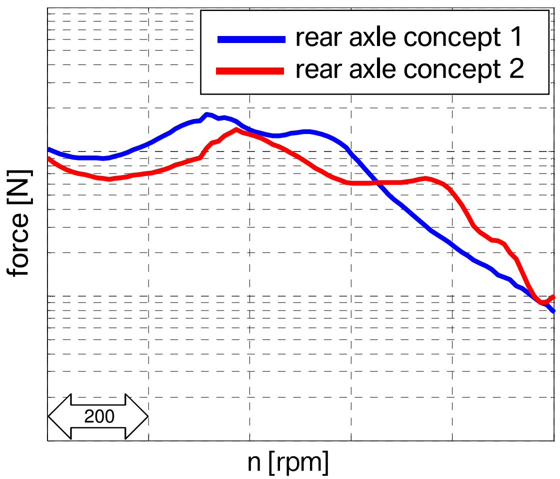
- Positioning/Number of the HAG Mounts
- Comparison of Different Rear Axle Concepts (see Example)



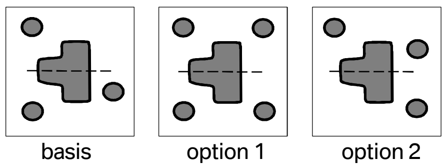
total vertikal force - rear axle carrier



total vertikal force - rear axle carrier

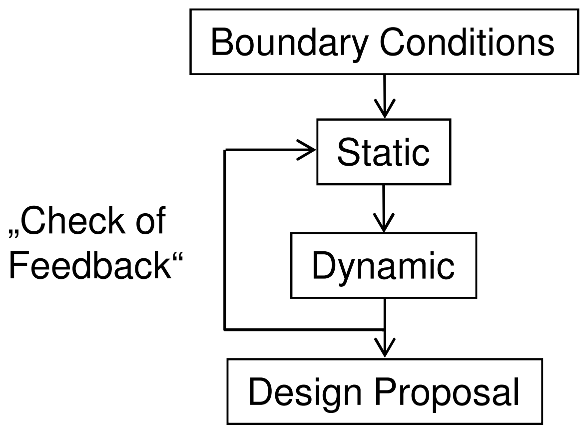


Topology Option: HAG Mounts



Aspects of Powertrain Acoustic Design
Basic Dimensioning – Approach, Static

Approach Sequence

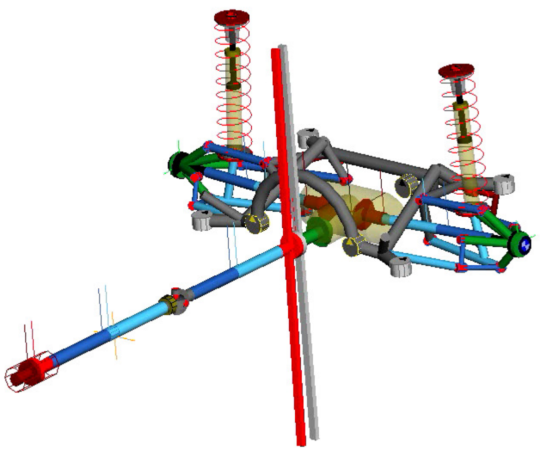


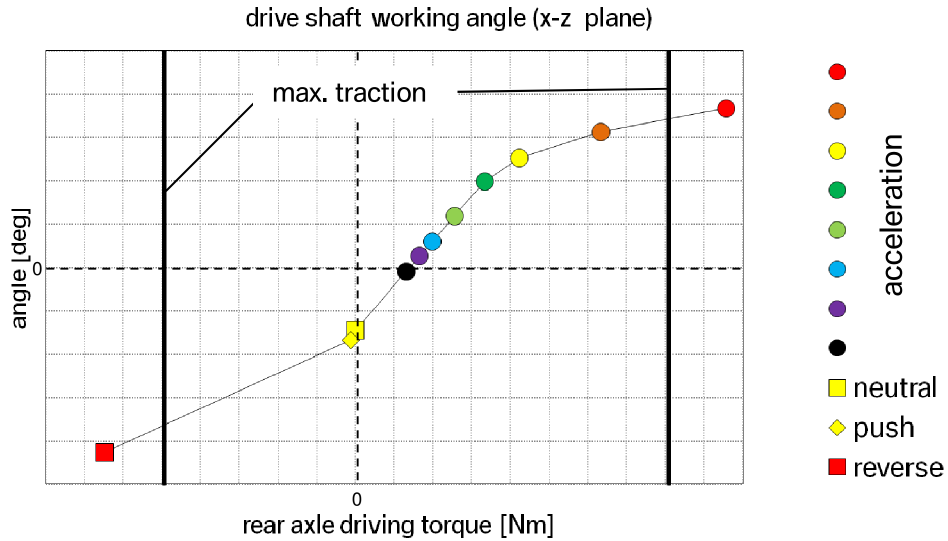
Axle Concept, Mount Position,
Traction and Powertrain Configuration

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

Stiffness Distribution, Rubber Characteristics, Dynamic Optimization

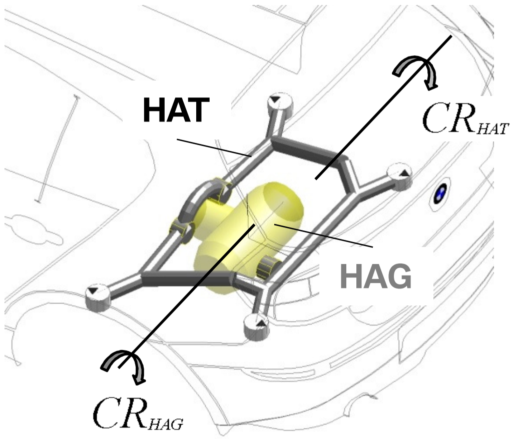
Basic Static Dimensioning



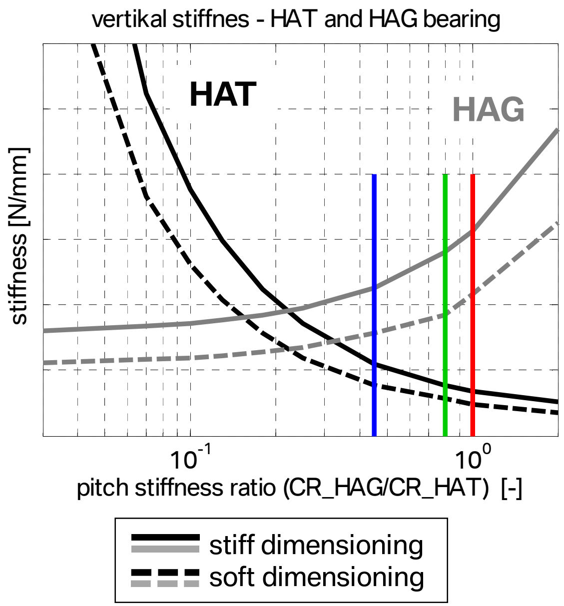


Aspects of Powertrain Acoustic Design
Basic Dimensioning – Dynamic

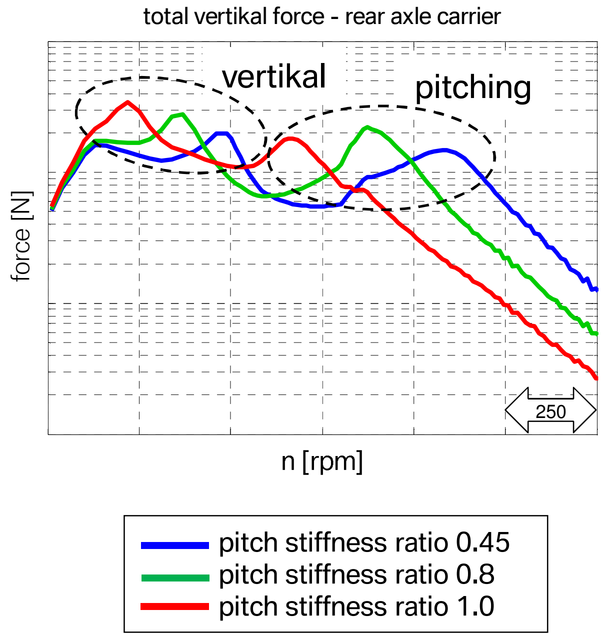
Optimal Pitch Stiffness Ratio HAT/HAG Mounts



$$\frac{1}{CR_{total}} = \frac{1}{CR_{HAT}} + \frac{1}{CR_{HAG}}$$



$$pitch\_stiffness\_ratio = CR_{HAG} / CR_{HAT}$$



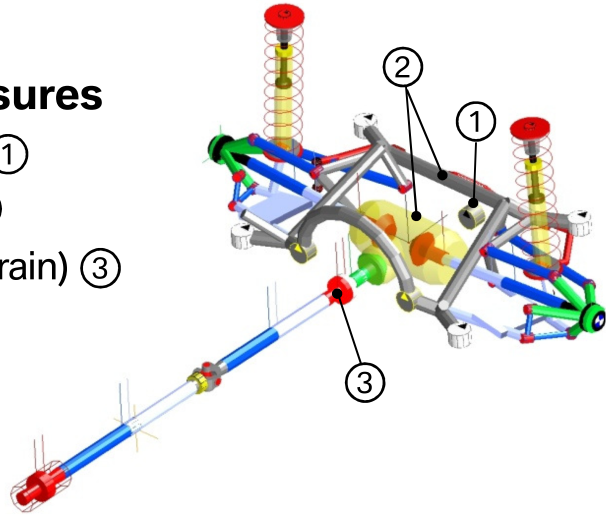
Detailed Dimensioning

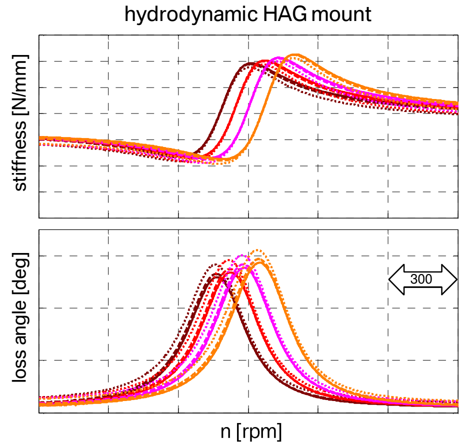
- Rubber Chracteristics
- Stiffness of the Secondary Mount Directions (lateral, longitudinal)

Aspects of Powertrain Acoustic Design
Optimization

Absorbance and Damping Measures

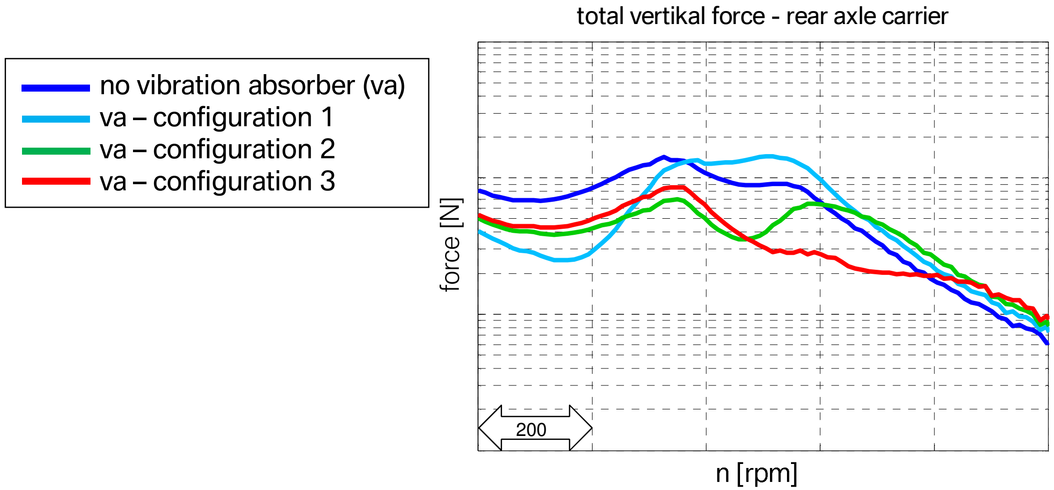
- Hydraulically Damped HAG Mounts ①
- Vibration Absorber at HAT or HAG ②
- Torsional Dynamic Absorber (Powertrain) ③

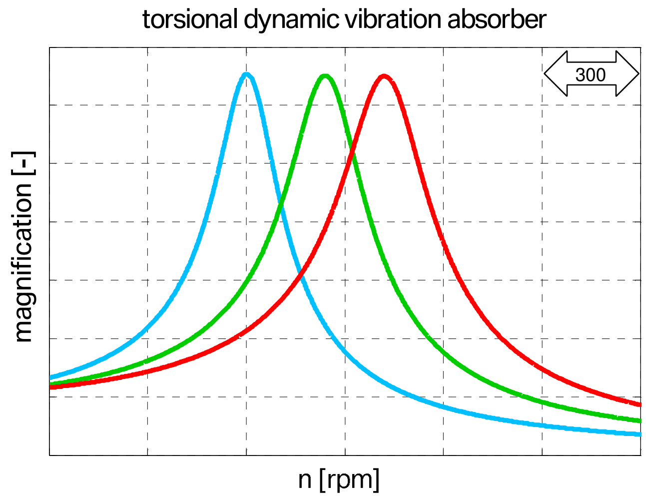




Example: Torsional Dynamic Vibration Absorber

- Influence of Tuning Frequency



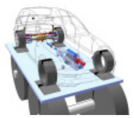


Aspects of Powertrain Acoustic Design
Contribution Analyses

SIMPACK TMB

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

Hybrid MBS Model



Frequency Sweep in Time Domain

State Space Model

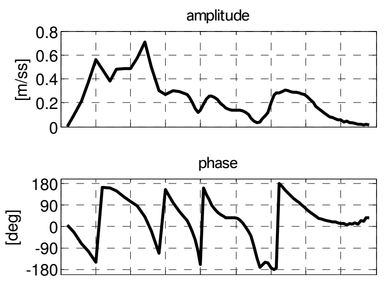
$$\frac{dx}{dt} = Ax + Bu$$
$$y = Cx + Du$$

Transfer Function H

Frequency Range

Coupling forces on TMB f

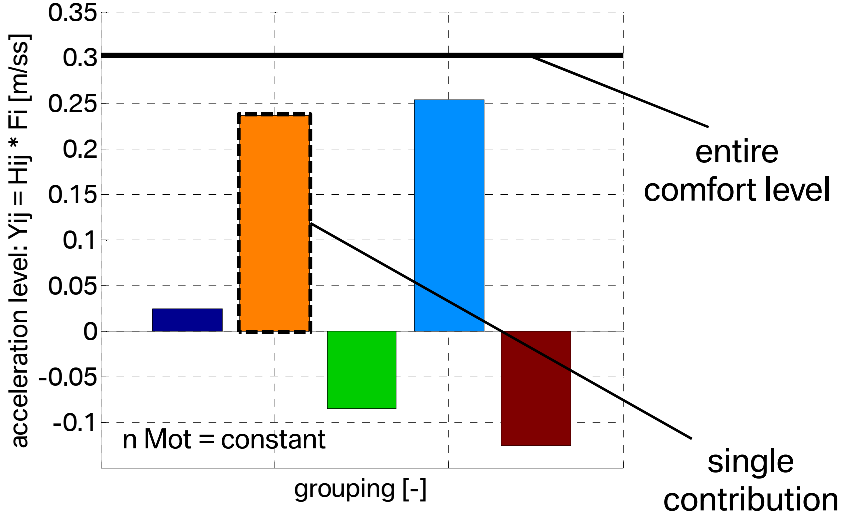
$$\mathbf{Y} = \mathbf{H} \times \mathrm{f}$$

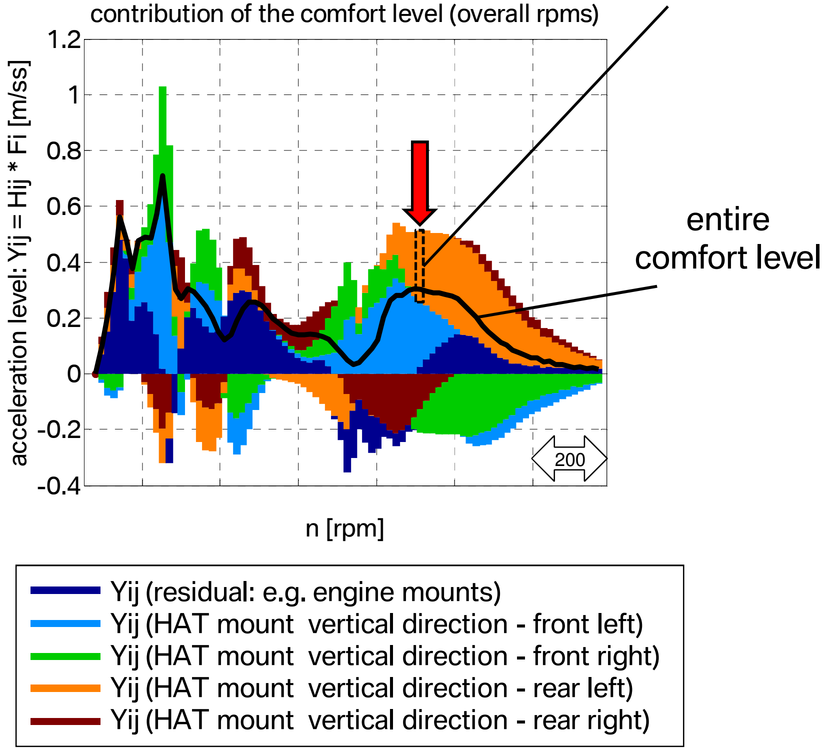


$$\begin{bmatrix} \mathbf{Y}_{FSS} \\ \mathbf{Y}_{Fedo} \\ \vdots \end{bmatrix} = \begin{bmatrix} \mathbf{H}_{11} & \mathbf{H}_{12} & \cdots \\ \mathbf{H}_{21} & \mathbf{H}_{22} & \\ \vdots & & \ddots \end{bmatrix} \begin{bmatrix} \mathbf{F}_{XSL} \\ \mathbf{F}_{YSL} \\ \vdots \end{bmatrix}$$

$$\mathbf{Y}_{FSS} = \underbrace{\mathbf{H}_{11}\mathbf{F}_{XSL}}_{\text{single contribution}} + \mathbf{H}_{12}\mathbf{F}_{YSL} + \ldots$$

single contribution





Powertrain Acoustics in the Full Vehicle Development
Summary / Further Steps

- 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.

Working with 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.