Booming Noise Optimization on an All Wheel Drive Vehicle

3rd International Conference
Dynamic Simulation in Vehicle Engineering, 22-23 May 2014, St. Valentin, Austria

Dr. Thomas Mrazek, ECS
Team Leader Vehicle Dynamics
• Motivation
• Process Overview
• Dyno Measurements
• Transfer Functions Measurements
• Dynamic Simulation Model
• Combined TPA
• Critical Transfer Path
• Conclusion
• Parameter Variation
Booming Noise Optimization

Motivation

Task of Investigation

• Basic vehicle was a 2WD vehicle without any noise problems
• Modification of the vehicle with 4WD (additional driven rear axle)
• Booming noise problem around 60 to 90 Hz
• “… noise coming from rear axle unit …”
• Root cause investigation
  • Experimental on roller test bench
  • Simulation with correlated full vehicle model
• Modifications of simulation model to point out improvement potential
Booming Noise Optimization
Process Overview

Vehicle Dyno

Transfer Path Analysis

Measured Transfer Functions

MBS Model

Simulated Excitation

Correlation

Critical Transfer Path

Sound Pressure on Driver’s Ear
Booming Noise Optimization
Dyno Measurement

ECS Dyno Specifications

- Power: 4 x 250 kW
- Wheel base: 2.0 to 4.4 m
- Track width: 1.1 to 2.3 m
- Max. axle load: 4500 kg

Operational Testing - Vehicle Dyno

- Full load run-up
- Different gears
- Different vehicle conditions
- Torsional vibration analysis

Analysis showed:
2nd engine order is dominating in interesting speed range
Trimmed Body Analysis

- Noise sensitivity functions
- Local dynamic stiffness
- Impedance measurements

at coupling points PT to body in all 3 directions

Transfer Functions

- From each coupling point to right driver’s ear
- Used for TPA in simulation
Booming Noise Optimization
Dynamic Simulation Model

Modeling of Full Vehicle in ADAMS/Car

Templates:

- Front axle
- Steering system
- Rear axle
- Engine + Mounts
- Gear box
- Driveline
- Body
- Tire + Roller test bench
Booming Noise Optimization
Dynamic Simulation Model

Modeling of Engine

- Model optimized for simulation time
- Torque due to 2\textsuperscript{nd} order gas forces between crank shaft and engine block
- Forces due to 2\textsuperscript{nd} order oscillating masses on engine block
- Nonlinear bushings for mounts and torque rods

Modeling of Gear Box

- Modeling of shaft+gears as rotational masses with torsional stiffness
- Kinematic couplers between gears
- All data (ratios, stiffness, mass moment of inertia) from detailed transmission model (AMESIM)
- Parameters adjusted for all shifted gears
Booming Noise Optimization
Dynamic Simulation Model

Excitation

- Measured ignition pressures
- Simulation with optimized engine model
- Comparison with measured engine full load torque characteristics
- Scaled to engine torque characteristics
- Reduced to 2\textsuperscript{nd} engine order

Starter Ring Gear

- Comparison of speed fluctuation
- Good correlation above 1500 rpm
- Interesting range 2000 to 3000 rpm
Sensitivity Study with ADAMS/Vibration

- Torsional stiffness of DMF, clutch, shafts
- Damping of DMF, clutch, shafts
- Mass moments of inertia

Modification of Parameter

- Mass moments of inertia of primary/secondary side of AWD clutch
- Damping of clutch
- Modified characteristics of engine mounts

Variation of clutch damping
Booming Noise Optimization
Dynamic Simulation Model

- Final check of correlation with engine run up in time domain

→ Adjusted model useable for engine run up simulation on roller test bench with excitation in dominating 2nd engine order
Method of Combined Transfer Path Analysis

Measured Excitation → MBS Simulation with adjusted model → Interface Forces in Time domain → Transformation in Frequency domain → Measured Transfer Functions

\[ p_i^m(j\omega) = F_k(j\omega) \cdot G_k^M(j\omega) \]
\[ \sum_k p_k^m(j\omega) = p^m(j\omega) \]

Input
- Excitation (ignition pressure, run-up ramp)
- Transfer Functions [Pa/N]

Output
- Sound pressure on driver‘s ear

Sound pressure of single path → Sound pressure on driver‘s ear
Booming Noise Optimization
Critical Transfer Path

Conditions

• Full load run up simulation of full vehicle
• Excitation of 2\textsuperscript{nd} engine order
• Closed AWD clutch
• On roller test bench

Noise Contribution Level of

• Front axle and engine mounts is dominating
• Rear axle level around 10 dB(A) lower

→ It is not possible that Booming noise comes from rear axle

All directions of all interface points
Only z-direction of all interface points
Z-direction of all front axle points
Z-direction of engine/gear box mounts
Z-direction of all rear axle points
Booming Noise Optimization

Conclusion

- Full vehicle model generated and correlated to measurement
- Good correlation for torsional vibrations of drivetrain and also ACC on engine/gear box/torque rod mounts
- Differences in acoustics behavior between 2WD and 4WD not due to additional masses or torsional stiffness of rear axle drive
- Highest levels on front axle → open Haldex® louder than closed
- In the area of front axle highest levels on rear mount (torque rod), in vertical direction

Based on these results different variants were investigated:

- Modified bushing properties of rear subframe
- Reduced excitation of 2\textsuperscript{nd} engine order
- Reduced load in direction of critical path
Booming Noise Optimization
Parameter Variation

Investigations of different variants in simulation

<table>
<thead>
<tr>
<th>Modifications</th>
<th>Reduction Potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modified characteristics of rear subframe bushings</td>
<td>0 dB(A)</td>
</tr>
<tr>
<td>Rear subframe bushings with higher damping</td>
<td>3 dB(A)</td>
</tr>
<tr>
<td>Implementation of a mass balancing system</td>
<td>10–15 dB(A)</td>
</tr>
<tr>
<td>New position of rear torque rod mount</td>
<td>6 dB(A)</td>
</tr>
</tbody>
</table>

Basic version (flexible subframe)
Mass balancing system MBS
Basic version + rigid subframe
Re-positioned torque rod
Torque rod + MBS
Booming Noise Optimization
Parameter Variation

• Rear mount for AWD version in a higher position
• Thus different angle of resulting supporting force
• In vertical direction higher load on front subframe and on body for AWD
• Transfer function in vertical direction around 15 dB(A) higher than in longitudinal direction

→ Root cause for Booming Noise
Booming Noise Optimization

Summary

• A simulation model was built up and correlated without any component measurement, only based on full vehicle run-up on roller test bench

• The introduced method of combined TPA is suitable to find out critical noise paths. Absolut assessment of noise needs more detailed and time consuming simulation models

• Based on simulation some improvements and their noise reduction potential were presented

• Design changes with highest influence were implementation of mass balancing system and modification of torque rod position/orientation

• Individual résumé:
good simulation works only in combination with good measurement

(… and vice versa 😊)
Thank you for your kind attention