Brake Squeal: A Challenge

Karthik Chittepu
1. Motivation
2. Background
3. Robustness Evaluation
Brake Noise Types

- Friction Noise
- Wire Brush
- Moan
- Hot Judder
- Squeal
- HF Squeal
- Groan

Drum Brakes

Disc Brakes

50Hz  500Hz  5000Hz

Courtesy: TRW
Motivation

- NVH field complaints and warranty costs
- Permanently increasing customer requirements and targets
- Complexity and Competition
- Correlation between simulation, bench and vehicle
Motivation

Courtesy: Daimler AG
### Operating Points

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Motivation

- CAE based robust design optimization helps in mitigating NVH risk by
  - Robustness Testing
  - Production NVH quality control

Target: Focused to find best solution taking into account the influence of the uncertain parameters

Courtesy: Daimler AG
CAD Model – Car Brake and Suspension

- Friction Material
- Backingplate
- Anchor (Caliper)
- Caliper
- Pistons
- Hub Unit
- Wheel Bearing
- Lower Arm
- Knuckle Brake Disc
- Tension Strut
- Steering Rod
- Wishbone

Courtesy: Daimler AG
Background: Brake Squeal Analysis

- Equation of motion:

\[ M\ddot{x} + C\dot{x} + Kx = 0 \]

where calculated Eigen values are \( \lambda = \alpha + i\ \omega \)

\( \alpha \) = Real part of solution = Damping coefficient

\( \omega \) = Imaginary part of solution

- \( x(t) = A * e^{\lambda t} = A * e^{(\alpha+i\omega)t} \)

\( = e^{\alpha t} (A_1 \cos \omega t + A_2 \sin \omega t) \)

- Stable/unstable modes:

\( \alpha < 0 \) Stable mode

\( \alpha > 0 \) Unstable mode

- Squeal Propensity:

\( g \gg -2\alpha / |\omega| = 2\alpha \)
Background: Brake Squeal Analysis

- Without Friction: Independent Eigenmodes
- Convergence of Eigenfrequencies with increasing $K$
- Mode Coupling at $K_{\text{crit}}$
- Unstable System (Squealing Propensity)
Why Robustness Analysis

- Noise problem identification
- Deterministic FE simulation was not able to find the critical frequency
- To find best solution taking into account the influence of uncertain parameters.
1. Define the Uncertainties:
   Ball Joints, Bearings stiffness, Material /Geometry, Brake Pressure

2. Simulate random parameters

3. Generate set of random specimen, replace in FE assembly to compute

4. Post processing
Robustness Evaluation: Material Tolerance

- Variation of all design parameters leads to a high variation not only in squeal propensity but also in the frequency at which instability occurs
- From the histogram, coefficient of variation is 118% which is extremely high
- The system is **NOT Robust**

![Graph showing variation in squeal coefficient and frequency](image)

Courtesy: Daimler AG
Robustness Evaluation: Geometric Tolerance

Map surface node to measurement (triangularization)

Define varying surface node

Interpolation, relaxation, repair of FE-mesh

Measure geometric deviations

Replace part in assembly

Imperfect Structure vs. Reference

Imperfection Z component
Geometrical tolerance has significant influence on results when compared to material tolerances.
Robustness Evaluation: Joint Tolerance

- Bearings, Ball Joints and Kinematic description

Courtesy: Daimler AG
Robustness Evaluation: Joint Tolerance

- Frequency identified
- Additional optimization to fix the problem
Conclusions

• optiSLang have completed the necessary methodology to support serial use for robust design optimization
• Brake squeal is a very complicated phenomena, due to this factor robustness analysis is important to understand its behaviour
• In the virtual model, the phenomenon which are found in the reality could be identified by robustness analysis
• Identification of problems early in the virtual prototyping stag
• CAE approach mitigates NVH risk in production and increases NVH model quality and robustness
  ➢ Better Identification of main influences
  ➢ Better prediction of system behavior
  ➢ Results fitting better with bench vehicles