Brake Moan Simulation using Flexible Methods in Multibody Dynamics

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Plan of Presentation

1) Introduction
2) Modeling
3) Results
4) Conclusion
Introduction

• General characteristics of brake moan
  – Low frequency noise phenomenon (<500 Hz)
  – Typically seen at very low vehicle speeds and brake pressures
  – Pad and disc stick momentarily and then release causing an excitation often transmitted to braking & suspension systems
  – Does not indicate a functional brake problem
  – Significant customer satisfaction issue resulting in costly warranty claims
Introduction

• Specific moan case studied
  – Rear brake on SLA trailing arm suspension
  – Fundamental frequency = 320 Hz
  – Off-braking
  – Most evident during extreme turning of loaded vehicle
  – Very low vehicle velocity (< 5 km/h)
  – Sensitive to bending characteristics of trailing arm (tie blade)

Introduction

• Several experimental measurements carried out to understand and describe the phenomenon (e.g. ODS, Modal Analysis etc.) on brake and tie-blade
• For deeper understanding of above phenomenon and as preventive action on forthcoming platforms, a virtual prototyping effort was launched
Introduction

- **Project Goals**
  - Create a multibody dynamic model of brake system
    - Rigid-body foundation brake components
    - Flexible representation of tie blade
  - Simulate moan phenomenon
  - Use model to test and design potential countermeasures
  - Model to serve as template for moan studies on future brake systems

Presentation Content

1) Introduction
2) Modeling
3) Results
4) Conclusion
Modeling

- Modeling Approach

<table>
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<tr>
<th>ADAMS</th>
<th>Geometry - Solid Model from CAD</th>
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<tbody>
<tr>
<td></td>
<td>Properties - Mass, Stiffness and Damping</td>
</tr>
<tr>
<td></td>
<td>- Mass from Solid Model</td>
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<td>- Stiffness from measurements or specifications</td>
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<td>- Damping from measurements or specifications</td>
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</tbody>
</table>

- Build Kinematic Model
- Add Dynamics; Contact, Friction, Compliances
- Validate
- Parameterize
- Design Studies

Model Components

- Foundation Brake
  - Rotor
  - Pads
  - Caliper
  - Piston
  - Anchor plate
  - Guide pins

- Suspension
  - Tie blades
  - Control arms
  - Springs
  - Shocks
  - Anti-roll bar
Modeling

Foundation disc brake: modeled as multi rigid-body system

Modeling

Suspension components – all rigid bodies, except tie blade (flexible)
Modeling

• Model Inputs
  – Rotor Velocity: 0-10.6 deg/s (vehicle 0.2 km/h) in 0.5 sec
  – Brake Pressure: constant 197kPa (approx. 2bar)

Modeling assumptions
  – All rigid bodies except tie blade
  – Only foundation brake modeled, no hydraulics
  – No thermal effects
  – No full-vehicle simulation; motion applied directly to rotor
Specific model elements
- Pad-to-Rotor contact
  - Normal force: controlled by ADAMS IMPACT function
  - Frictional force: $F_{\text{fr}} = \mu(v) \cdot F_{\text{n}}$
    - $\mu_{\text{static}} = 0.5$
    - $\mu_{\text{dynamic}} = 0.37$
• Specific model elements
  – Flexible tie blade
    • Physically, moan known to be sensitive to bending characteristics of tie blade
    • Unable to replicate moan with rigidly modeled tie blade
    • Import modal data from FE model of tie blade to ADAMS model
    • Constrain FE tie blade in ADAMS and upon it mount rigid-body brake model
Results

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**Results**

- Model output considerations
  - Time domain moan signal
  - Frequency domain moan signal
  - Mode shape animation
Results

- Model output characteristic of moan
  - Acceleration on caliper and along tie blade
  - Stick-slip pulses followed by sustained vibration
  - Fundamental frequency in 300Hz range
- Frequency comparison

<table>
<thead>
<tr>
<th>Test Point</th>
<th>ADAMS Model Moan Frequency</th>
<th>Physical Test Data Moan Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Point A: forward, high on tie blade</td>
<td>268 Hz</td>
<td>312 Hz</td>
</tr>
<tr>
<td>Point B: forward, low on tie blade</td>
<td>268 Hz</td>
<td>312 Hz</td>
</tr>
<tr>
<td>Point C: middle, low on tie blade</td>
<td>268 Hz</td>
<td>312 Hz</td>
</tr>
<tr>
<td>Point D: top of caliper, near guide pin</td>
<td>268 Hz</td>
<td>312 Hz</td>
</tr>
</tbody>
</table>
**Moan Profile: model results**

![Tangential Caliper Acceleration Time History](image1)

![Tangential Caliper Acceleration Frequency Spectrum](image2)

**Moan Profile: experimental test data**

![Tie Blade Acceleration](image3)

![Lateral Tie Blade Acceleration (squared) Spectrum at point 0.0112](image4)
Results

• Mode shape animation
  – Tie blade bending mode natural frequency (free-free) = 262Hz
  – Simulated system natural frequency = 268 Hz

Results

• Model response to moan countermeasures
  – Removal of anti-rattle clip
    • experimental: reduced moan occurrence
    • model: no moan

  – Swaged tie blade
    • experimental: reduced moan occurrence
    • model: no moan
Results

- Model response to input variations
  - Brake pressure increase
    - experimental: no moan
    - model: no moan
  - Rotor velocity increase
    - experimental: no moan
    - model: no moan

Results
Conclusion

Model reasonably replicated the moan signal
Successful comprehensive model validation
  – Response to known countermeasures
  – Response to input variations
Flexible Multi-body dynamics approach allows for faster simulation time versus FE-only method
  – Use flexible bodies only where needed
  – Baseline model runs in ~1.5 hours on Pentium II NT workstation
Conclusion

- Model usable for additional exploration
  - Parametric sensitivity studies
  - Guide to physical experimentation
  - Address future warranty issues
- Template for future brake system modeling
- Combined finite element and multibody dynamic simulation models are essential to successful brake vibration simulation