STRUCTURAL OPTIMIZATION OF MECHANICAL SYSTEMS
PROJECT DESCRIPTION

Subject
• Topology Optimization with Parametrization of Hardpoint Positions (joint positions)

Tasks
• Develop a simplified FE-model of the wheel suspension system (Abaqus)
  • Validate with respect to force signals
• Propose concept load cases for optimization
• Optimize the system model w.r.t. stiffness and weight (Tosca)
• Prestudy for TO with parametrization of hardpoint positions
  • Simpler Two-link problem
Two main loops

- **System phase**
  - Tuning of hardpoint positions (joint positions)

- **Component phase**
  - Analysis
  - Testing
  - Optimization (Topology, Shape, Size)

**Optimizations today**

- **Component level**
  - Predetermined Boundary Conditions
  - Narrow solution space

**Optimizations in the future**

- **System phase**
  - Broaden the solution space
  - Include hardpoint positions within the optimization
SYSTEM COMPONENTS AND HARDPOINT POSITIONS

1) Knuckle
2) Upper Control Arm (UCA)
3) Lower Control Arm (LCA)
4) Toelink
5) Subframe
6) Leaf spring

• Hardpoints for linkages
BOUNDARY CONDITIONS AND EXTERNAL LOADS

Boundary Conditions

• Similar to a chassis rig
  • Inner bodies of bushings are fixed
  • Elastic bushings enables relative movement

External Loads

• Knuckles
• Dampers
  • Quasi-static analysis - No velocity
  • Damping characteristics has no effect
STRENGTH EVENTS – BIP (RLD)
STRENGTH EVENTS – DOC (RLD)
STRENGTH EVENTS – SAC (RLD)
• Apply outer loads
• Read forces in other hardpoints
  • Compare with RLD
• Global reference frame
• Overall good correlation
Wheel Suspension System

- Linkages as design volumes
- Given parameters on suspension system

Simple two-component model

- Try different optimization setups
- Parametrization of hardpoint
**Introduce an outer parametric loop**

- Parameters (hardpoint positions)
  - Follows a DOE
- Save results for the current configuration
  - Optimized Geometry
  - Performance measurement (objective function)

**What do we get?**

- A structural optimization process
  - Target system weight at an early stage

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**Diagram:**

1. **DOE (Design Of Experiments)**
   - for each set of parameter values $p_i$ in DOE
2. Parametrized FE-model
   - Including concept load cases
3. Topology Optimization
4. Save optimized objective function $f_i$
5. Compare $f_i$ for different $p_i$
   - Data and ideas for concept decisions

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**Note:**

- **Parametrization + Non-Parametric Optimization**
- **Topology Optimization**
- **Parametrized FE-model**
- **DOE (Design Of Experiments)**
MINIMIZE SYSTEM MASS (RIGID BUSHINGS)

Minimize mass (Rigid bushings)

100mm

$\Delta \leq 1\text{mm}$

System weight

Mass [kg]

Hardpoint position [mm]
MINIMIZE SYSTEM MASS (ELASTIC BUSHINGS)

Minimize mass (Elastic bushings)

\[ \Delta \leq 10\text{mm} \]

Minimize mass (Elastic bushings)

100\text{mm}
MINIMIZE STRAIN ENERGY (ELASTIC BUSHINGS)

Minimize strain energy
Mass: 1.35 kg
(Elastic bushings)

Strain energy

[Graph showing strain energy vs. hardpoint position]
Minimize Mass
+ Suitable for performance measurement
- Not as nice geometrical results
- Not as numerically stable

Minimize Strain Energy
+ Better geometrical results
+ Numerically stable
- Not very easy to understand and communicate
Optimization Strategies – What to Use

Parametrization of hardpoint position

- Minimize Mass
  - The goal is to save weight and fulfill system requirements

For given hardpoint positions

- Minimize Strain Energy
  - If needed, to refine topology
  - Iterate with mass constraints
OPTIMIZATION WHEEL SUSPENSION SYSTEM

• Minimize Strain Energy
• Mass Constraint: $M^{\text{OPT}} \leq M^{\text{REF}}$
• Displacement Constraints
  • Knuckle (HP9)
• Load Cases – based on peak loads
  • BIP
  • DOC
  • SAC
• Symmetry Constraint
WHEEL SUSPENSION SYSTEM - MINIMIZE STRAIN ENERGY

- Result of Strain energy [Nm]

<table>
<thead>
<tr>
<th>Opt system</th>
<th>Ref model</th>
<th>Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>BIP</td>
<td>186</td>
<td>187</td>
</tr>
<tr>
<td>DOC</td>
<td>233</td>
<td>283</td>
</tr>
<tr>
<td>SAC</td>
<td>408</td>
<td>411</td>
</tr>
<tr>
<td>Sum</td>
<td>827</td>
<td>881</td>
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</table>
# Mass Distribution

- **Mass [kg]**

<table>
<thead>
<tr>
<th></th>
<th>Opt system</th>
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<th>Change</th>
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</thead>
<tbody>
<tr>
<td>LCA</td>
<td>5.55</td>
<td>5.22</td>
<td>6.4%</td>
</tr>
<tr>
<td>UCA</td>
<td>0.73</td>
<td>1.19</td>
<td>-38.7%</td>
</tr>
<tr>
<td>Toelink</td>
<td>0.66</td>
<td>0.59</td>
<td>13.0%</td>
</tr>
<tr>
<td>Sum</td>
<td>6.95</td>
<td>7.00</td>
<td>-0.8%</td>
</tr>
</tbody>
</table>
ITERATE MASS CONSTRAINT

- Iterate mass constraint until displacement constraints are no longer fulfilled
- Displacement Constraints
  - BIP – Longitudinal
  - DOC – Vertical
  - SAC – Lateral
- Only for illustrative purposes

<table>
<thead>
<tr>
<th>Strain energy [Nm]</th>
<th>0.9(\bar{M}_{\text{Ref}})</th>
<th>0.8(\bar{M}_{\text{Ref}})</th>
<th>0.7(\bar{M}_{\text{Ref}})</th>
<th>0.6(\bar{M}_{\text{Ref}})</th>
<th>0.5(\bar{M}_{\text{Ref}})</th>
</tr>
</thead>
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<tr>
<td></td>
<td>-4.2%</td>
<td>1.9%</td>
<td>7.4%</td>
<td>25.2%</td>
<td>121.7%</td>
</tr>
</tbody>
</table>

<table>
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<tr>
<th>Displacements constraints [mm]</th>
<th>Ok</th>
<th>Ok</th>
<th>Ok</th>
<th>Ok</th>
<th>Not Ok</th>
</tr>
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**ITERATE MASS CONSTRAINT**

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</table>

| Displacements constraints [mm] | Ok | Ok | Ok | Ok | Not Ok |

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**PROPOSED METHOD**

**Proposal**
- System phase
- Topology Optimization with Parametrization of Hardpoint Positions
  - Broader solution space
  - Mass distribution between components

**Further work**
- Correlation with respect to displacements

**Embrace the Future**
- Efficient system level optimizations
  - Increased performance of products
  - Reduced costs of development
THANK YOU!