Sensitivity Study
Design Optimization
Probabilistic Analysis
of a
Rotor Brake System

OptiY GmbH - Germany
Design Specifications

**Design Parameter Space:**
- Wall High = [6, 10] mm
- Pad Thickness = [0.8, 1.2] mm
- Brake Thickness = [0.8, 1.2] mm

Geometry Tolerances = 0.1 mm
With Normal Distribution

**Fix Process or Environment Parameters:**
- Operating Temperature = 100 ± 50 °C
- Ambient Temperature = 22 ± 20 °C
- Material Density = 7850 ± 150 kg m⁻³
- Thermal Expansion = 1.2E⁻⁵ ± 3E⁻⁷ °C⁻¹
- Young’s Modulus = 2E¹¹ ± 5E⁹ Pa

**Functional Requirements:**
- Contact Pressure = maximal as possible

**Initial Nominal Parameters**

<table>
<thead>
<tr>
<th>Name</th>
<th>Nominal</th>
<th>Tolerance</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating Temp</td>
<td>100</td>
<td>100</td>
<td>°C</td>
</tr>
<tr>
<td>Ambient Temp</td>
<td>22</td>
<td>40</td>
<td>°C</td>
</tr>
<tr>
<td>Wall High</td>
<td>8</td>
<td>4</td>
<td>mm</td>
</tr>
<tr>
<td>Pad Thickness</td>
<td>1</td>
<td>0.4</td>
<td>mm</td>
</tr>
<tr>
<td>Brake Thickness</td>
<td>1</td>
<td>0.4</td>
<td>mm</td>
</tr>
<tr>
<td>Density</td>
<td>7850</td>
<td>300</td>
<td>kg m⁻³</td>
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<tr>
<td>Thermal Exp.</td>
<td>1.2E⁻⁵</td>
<td>6E⁻⁷</td>
<td>°C⁻¹</td>
</tr>
<tr>
<td>Young’s Modulus</td>
<td>2E¹¹</td>
<td>1E⁺¹⁰</td>
<td>Pa</td>
</tr>
</tbody>
</table>
Nominal FE-Simulation

Temperature
Operating Point = 100 °C

Total Deformation
Max = 3.19 mm
Nominal FE-Simulation

Equivalent Stress
Max = 50970 MPa

Equivalent Strain
Max = 0.24
Nominal FE-Simulation

Contact Status

Contact Pressure
Max = 11979 MPa
Nominal FE-Simulation

Frictional Stress
Max = 2021 MPa

Sliding Distance
Max = 0.146 mm
Design Space: 2D Section Diagrams

- Wall Height
- Pad Thickness
- Brake Thickness
- Operating Temperature

Pressure and Frictional Stress Graphs
Design Space: 3D Graphics

Contact Pressure

Contact Frictional Stress
Global Sensitivity: Parameter Importance [%]

**Stress**
- Brake Thickness: 77.81%
- Pad Thickness: 60.77%
- Thermal Expansion: 9.04%
- Wall High: 1.08%
- Density: 0.99%
- Youngs Modulus: 0.72%
- Ambient Temperature: 0.49%
- Operating Temperature: 0.31%

**Deformation**
- Brake Thickness: 50.84%
- Pad Thickness: 37.44%
- Wall High: 13.17%
- Operating Temperature: 6.58%
- Ambiant Temperature: 5.27%
- Thermal Expansion: 2.68%
- Density: 0.22%
- Youngs Modulus: 0.19%

**Frictional Stress**
- Pad Thickness: 48.99%
- Brake Thickness: 35.11%
- Ambient Temperature: 15.08%
- Density: 11.57%
- Operating Temperature: 9.96%
- Wall High: 9.12%
- Youngs Modulus: 8.95%
- Thermal Expansion: 8.13%

**Pressure**
- Pad Thickness: 43.87%
- Thermal Expansion: 29.66%
- Ambient Temperature: 17.41%
- Brake Thickness: 14.39%
- Youngs Modulus: 11.33%
- Operating Temperature: 11.21%
- Wall High: 10.83%
- Density: 9.83%

The diagrams show the total effect and main effect for each parameter.
Global Sensitivity: Parameter Interaction [%]
Nominal Design Optimization

Optimization Goal:
- Criteria: Maximize the Contact Pressure

Nominal Design:
- Contact Pressure = 24376 MPa
- Contact Frictional Stress = 4870 MPa

<table>
<thead>
<tr>
<th>Design Parameters</th>
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<th>Tolerance</th>
<th>Unit</th>
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<tr>
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<tr>
<td>Ambient Temperature</td>
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<tr>
<td>Wall High</td>
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<td>Youngs Modulus</td>
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<td>1e⁺⁰¹⁰</td>
<td>Pa</td>
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</table>
Uncertainty Parameters and Tolerances

- Operating Temperature
- Ambient Temperature
- Density
- Thermal Expansion
- Young's Modulus
- Wall Height
- Ped Thickness
- Brake Thickness
Probabilistic Analysis

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Skewness</th>
<th>Kurtosis</th>
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<tr>
<td>Pressure</td>
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<tr>
<td>Stress</td>
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<tr>
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<tr>
<th>Sigma</th>
<th>Variance</th>
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<td>Equation</td>
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Design Sensitivity

**Stress**
- Pad Thickness
- Brake Thickness
- Thermal Expansion
- Density
- Ambient Temperature
- Wall High
- Youngs Modulus
- Operating Temperature

**Deformation**
- Brake Thickness
- Pad Thickness
- Ambient Temperature
- Density
- Thermal Expansion
- Wall High
- Youngs Modulus
- Operating Temperature

**Frictional Stress**
- Pad Thickness
- Brake Thickness
- Density
- Ambient Temperature
- Wall High
- Youngs Modulus
- Thermal Expansion
- Operating Temperature

**Pressure**
- Pad Thickness
- Ambient Temperature
- Brake Thickness
- Youngs Modulus
- Thermal Expansion
- Density
- Operating Temperature
Conclusion

Global sensitivity study based on the nonlinear meta model identifies significant design, environment or process parameters and its interactions.

Design optimization based on the meta model using adaptive Gaussian process is very fast and efficient.

Considering uncertainty parameters and tolerances, probabilistic analysis computes the stochastic distributions of the design goals. The design sensitivity shows the cause-effect-chain for the variability of the contact pressure.

OptiY® is the leading software platform for design optimization of all engineering fields using different commercial CAD/CAE-software or in-house codes.