Impact of Elasticity on the Transmission Behaviour of Thin Ring Gears

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Benjamin Kiess, M.Eng.
Impact of Elasticity on the Transmission Behaviour of Thin Ring Gears

1. Research
2. Motivation
3. Modelling setup
4. Results
5. Conclusion
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Research Activity and Focus

1. Research

   • Holistic analysis of static and dynamic behaviour of mechatronical drivetrains
   • Strength and fatigue calculations using analytics and numerics

2. Motivation

3. Modelling setup

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Research Activity and Focus

1. Research
   - Predictive Maintenance using MBS and FEM to:
     - Analyse current system status (real and virtual condition monitoring)
     - Calculate durability on demand (offline) and realtime (online)
     - Active and passive control systems predicting system behavior (L-/NMPC)

2. Motivation

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5. Conclusion
Motivation
Transmission behaviour of a gear stage

- Influenced by geometry and material
  - Stiffness of tooth body
  - Stiffness of tooth bending
  - Stiffness due to Hertzian pressure
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**Different approaches for simulation of gearboxes**

- Rigid gear wheels
  - No deformation of gear wheels
  - System stiffness combined in force element
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Different approaches for simulation of gearboxes

- Flexible gear wheels
  - System stiffness is combination of force element and bodies (modal)
  - Consideration of eigenmodes
  - Calculation of load distribution
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When should one use which approach?

1. Research
   - When does the deformation of the gear wheels affect the transmission behaviour of the system?
     - Correlation between basic gear wheel parameters and deformation?

2. Motivation
   - Analyses at typical planetary gearboxes of wind turbines having thin ring gears
   - Usage of fully flexible, parametrized FE-models
     - Automatic structured mesh generation

3. Modelling setup

4. Results

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Modelling Setup

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Usage of independent parameters for evaluation

- Ring thickness $s_r$ depending on module $m_n$ (parameter of geometry)
- Transmission error (parameter of system behaviour)

Usage of independent parameters for evaluation

- Ring thickness $s_r$ depending on module $m_n$ (parameter of geometry)
- Transmission error (parameter of system behaviour)
Definition of design parameters and their variation

- Variable parameters:
  - $i_{21}$ Gear ratio
  - $z_1$ Number of teeth on ring gear
  - $m_n$ Module
  - $s_r$ Ring thickness

- Fix parameters:
  - $x_1 = x_2 = 0$ Shift factor
  - $\beta = 0^\circ$ Helix angle
  - $b = 10\ mm$ Tooth width
# Impact of Elasticity on the Transmission Behaviour of Thin Ring Gears

## 1. Research

### Definition of parameters and their variation

<table>
<thead>
<tr>
<th></th>
<th>$i_{21}$</th>
<th>-4</th>
<th>-5</th>
<th>-6</th>
</tr>
</thead>
<tbody>
<tr>
<td>$m_n$</td>
<td>2</td>
<td>3</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>$s_r$</td>
<td>1,5$m_n$</td>
<td>2$m_n$</td>
<td>3$m_n$</td>
<td>5$m_n$</td>
</tr>
<tr>
<td>$i_{21}$</td>
<td>$z_{1,1}$</td>
<td>$z_{1,2}$</td>
<td>$z_{1,3}$</td>
<td>$z_{1,4}$</td>
</tr>
<tr>
<td>-4</td>
<td>-120</td>
<td>-112</td>
<td>-104</td>
<td>-96</td>
</tr>
<tr>
<td>-5</td>
<td>-120</td>
<td>-115</td>
<td>-110</td>
<td>-105</td>
</tr>
<tr>
<td>-6</td>
<td>-120</td>
<td>-108</td>
<td>-96</td>
<td>-84</td>
</tr>
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</table>

## 2. Motivation

### Number of Calculations

<table>
<thead>
<tr>
<th></th>
<th>$i_{21}$</th>
<th>$m_n$</th>
<th>$s_r$</th>
<th>$z_1$</th>
<th>$\Pi$</th>
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</thead>
<tbody>
<tr>
<td>3</td>
<td>4</td>
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<td>4</td>
<td>192</td>
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</tr>
</tbody>
</table>
Results
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Deformation of ring gear depending on ring thickness

- Deformation of ring gear decreases with increasing ring thickness

\[
1.5 \cdot m_n, \quad 2 \cdot m_n, \quad 3 \cdot m_n, \quad 5 \cdot m_n
\]
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Transmission Behaviour – Transmission Error (Variation of Module $m_n$)

$$m_n = 2, z_1 = -105$$

$$m_n = 5, z_1 = -105$$

$$m_n = 3, z_1 = -105$$

$$m_n = 8, z_1 = -105$$
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Transmission Behaviour – Transmission Error (Variation of Module $m_n$)

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Average Transmission Error [°]

$s_r = x \cdot m_n$

$m_n = 2, z_1 = -105$

$m_n = 3, z_1 = -105$

$m_n = 5, z_1 = -105$

$m_n = 8, z_1 = -105$

$s_r = x \cdot m_n$
1. Research

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Transmission Behaviour – Transmission Error (Variation of No. of T. $z_1$)

$m_n = 8, z_1 = -105$

$m_n = 8, z_1 = -115$

$m_n = 8, z_1 = -110$

$m_n = 8, z_1 = -120$
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Professor for Computer Aided Engineering
Anhalt University of Applied Sciences

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Transmission Behaviour – Validation of Results

- Comparison between theoretic TE and experimental TE

<table>
<thead>
<tr>
<th></th>
<th>FEM</th>
<th>Weber/Banaschek (WB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmission Error [°], (i = -5, z_1 = 105, z_p = 42, m_n = 8, s_r = 1.5 \cdot m_n)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0,1142 °</td>
<td>0,113 °</td>
<td></td>
</tr>
<tr>
<td>100 %</td>
<td>99,12 %</td>
<td></td>
</tr>
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</table>

- Theoretic system stiffness, FE-stiffness and SIMPACK-stiffness

<table>
<thead>
<tr>
<th></th>
<th>WB</th>
<th>DIN 3990</th>
<th>FEM</th>
<th>SIMPACK (WB)</th>
<th>SIMPACK (DIN)</th>
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<tr>
<td>Stiffness (c' \ [\text{N/mm(\mu m)}], i = -5, z_1 = 105, z_p = 42, m_n = 8, s_r = 1.5 \cdot m_n)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>14,52</td>
<td>15,71</td>
<td>14,67</td>
<td>14,52</td>
<td>15,31</td>
<td></td>
</tr>
<tr>
<td>100 %</td>
<td>108 %</td>
<td>101 %</td>
<td>100 %</td>
<td>105 %</td>
<td></td>
</tr>
</tbody>
</table>
Conclusion
Conclusion

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- Validated relation between chosen geometry and transmission error (TE)
- Convergence of TE with increasing ring thickness
- Reduction of TE with increasing $m_n$ and increasing $i_{21}$

Variation of $m_n$

Variation of $i_{12}$
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Recommendations

- Flexible Approach recommended for ring thicknesses of $s_r < 7 \cdot m_n$

| $z$ | $|z| < 100$ | $|z| > 100$ |
|-----|-------------|-------------|
| $s_r [mm]$ | $7 \cdot m_n$ | $8 \cdot m_n$ |
Thank You!