Simulation Method for the Characterisation of Torque Transducers

IMEKO XXII World Congress
Stefan Kock, Georg Jacobs, Dennis Bosse, Florian Strangfeld
Belfast, 04.09.2018
## Structure

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2. Approach  
3. Results  
4. Summary
Motivation and Objective

Achieved measurement uncertainty

- Strain gauges transducers 2% - 5%

Required measurement uncertainty

- Efficiency measurement < 0.5%

MNm torque measurement in wind turbine test benches

- No state of the art – custom made transducers
- No calibration methods above 1.1 MN·m

Influence of system-dependent influences not known

- high multi-axial operation loads, rotation speed,
- assembly process, temperature fluctuation

High measurement uncertainty

Knowledge of system-dependent influences will improve torque measurement

Objective

Creating a simulation method for the characterisation of the torque transducers to quantify the influence of system-dependent parameters on torque measurement
Approach

<table>
<thead>
<tr>
<th>Definition of FEM Model Parameters</th>
<th>Simulation of Strain Gauges &amp; Circuit</th>
<th>Application of the Method</th>
<th>Validation of the Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mesh Density</td>
<td>Strain Gauges</td>
<td>4 kN·m Transducer (custom made)</td>
<td>RWTH Tests &amp; PTB Calibration</td>
</tr>
<tr>
<td>Element Type</td>
<td>Electrical Circuit</td>
<td>Modeling of</td>
<td>Variation of</td>
</tr>
<tr>
<td>Meshing Strategy</td>
<td></td>
<td>transducer</td>
<td>Temperature</td>
</tr>
<tr>
<td>Geometry Simplifications</td>
<td></td>
<td>test rig</td>
<td>Strain gauge (SG)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>adhesive</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>SG application pressure</td>
</tr>
</tbody>
</table>

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## Results

Strain Gauge Simulation in Finite Element Method

<table>
<thead>
<tr>
<th>Modeling Effort</th>
<th>Point</th>
<th>Spring</th>
<th>Multi-Spring</th>
<th>Shell</th>
<th>3D-Detailed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>Low</td>
<td>Average</td>
<td>Average</td>
<td>Low</td>
<td>Very High</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Computational Time</th>
<th>Very Low</th>
<th>Very Low</th>
<th>Very Low</th>
<th>Very Low</th>
<th>Very High</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Post-processing Effort</th>
<th>High</th>
<th>Very Low</th>
<th>Very Low</th>
<th>Average</th>
<th>Very High</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Applicability on Non-homogeneous Strain Fields (SF)</th>
<th>X</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Applicability on Independence of Mesh</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Applicability on Applicable for</td>
<td>All geometries (homogeneous strain field (SF))</td>
<td>All geometries (conditionally homogeneous SF)</td>
<td>All geometries (conditionally homogeneous SF)</td>
<td>All geometries (inclusive non-homogeneous SF)</td>
<td>Optimization of strain gauges grid</td>
</tr>
</tbody>
</table>

- **Not Suitable**
- **Conditionally Suitable**
- **Suitable**
Results
Custom-made 4 kN∙m Torque Transducer

Transducer Body
- Adaptation Flange
- 51CrV4+A
- Transducer Body
- Stamp Pad (2cm x 2.5cm)
- 200 mm
- 90 mm

Application of Strain Gauges
- Guidance
- Guided Stamp
- Foundation
- Transducer Support

Strain Gauge Circuit
- Adhesive
- Application Pressure
- Methacrylat
- 0.638 bar
- Methacrylat
- 1.275 bar
- Cyanoacrylat
- 0.638 bar
- Cyanoacrylat
- 1.275 bar
- Epoxy Resin (thermosetting)
- 1.275 bar

Foundation
- Solder Terminal
- Strain Gauge
- Guided Stamp

Application of Strain Gauges

Transducer Body

Guidance

Guided Stamp

Stamp Pad

(2cm x 2.5cm)

Transducer Support

Strain Gauge

Solder Terminal

Mt

β

270° 0° 90°
Results

Custom-made 4 kN·m Torque Transducer
Results
Determination of material parameters

Determination of Young Modulus

Up to 10.5% fluctuation of the Young Modulus

<table>
<thead>
<tr>
<th>Specimen Type</th>
<th>Relative Uncertainty per Specimen [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Longitudinal 1</td>
<td>Up to 10.5%</td>
</tr>
<tr>
<td>Longitudinal 2</td>
<td>Up to 10.5%</td>
</tr>
<tr>
<td>Longitudinal 3</td>
<td>Up to 10.5%</td>
</tr>
<tr>
<td>Lateral 1</td>
<td>Up to 10.5%</td>
</tr>
<tr>
<td>Lateral 2</td>
<td>Up to 10.5%</td>
</tr>
</tbody>
</table>

Young Modulus [GPa]

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<tr>
<th>Specimen Type</th>
<th>Young Modulus [GPa]</th>
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<tbody>
<tr>
<td>Longitudinal 1</td>
<td></td>
</tr>
<tr>
<td>Longitudinal 2</td>
<td></td>
</tr>
<tr>
<td>Longitudinal 3</td>
<td></td>
</tr>
<tr>
<td>Lateral 1</td>
<td></td>
</tr>
<tr>
<td>Lateral 2</td>
<td></td>
</tr>
</tbody>
</table>

Relative uncertainty per specimen [%]

Longitudinal specimens

Lateral specimens
**Results**

**Validation**

<table>
<thead>
<tr>
<th>Deviation (Mean)</th>
<th>6.9%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deviation (Min)</td>
<td>1.3%</td>
</tr>
</tbody>
</table>

Simulation Uncertainty

- k - strain gauge factor
- Strain gauge position
- ≈1%

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Summary

- Custom-made transducer – Classification acc. to DIN 51309 is 0.2
- Deviation of simulation to measurement results
  - mean 6.9 % and minimal 1.3 %
- Validated simulation method can be used to estimate crosstalk-effects on torque measurement
- Material properties have large influence on simulation results
- Young modulus can variate over the circumference up to 10.5 %
- Adhesive and strain gauge application pressure have low influence on torque signal (in case of introduced investigations)
Thank you for your attention.

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