Thermal mixing and fatigue experiment:
Solving inverse heat conduction problems using experimental data

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Overview

1) Description of the experimental setup [last SKC Symposium]
2) Temperature measurement [last SKC Symposium]
3) Inverse heat conduction problem
4) Other tasks / projects
1) Test section

Turbulent thermal mixing → High-cycle thermal fatigue
Frequencies of interest = 0.01 – 5 Hz
Aim = collect exp. data \( T(x_{n}, t^{P}) \) \( \rightarrow \) CFD models \( T(x,t) \) \( \rightarrow \) fatigue cracking models
1) Test section, inner tube & thermocouple discs
2) Thermocouple discs & rod motion

- Disc diameter: 11.90 mm
- Disc max. height: 4.70 mm
- Hole max. diameter: 1.02 mm
- Distance from holes to Q: 3.00 mm
- Hole depth: from 0.35 mm to thru

Right thermocouple disc
2) Measured temperatures

- H2 at 0.72 m and 45° for Case 1
- H2 at 0.67 m and 45° for Case 1
- H2 at 0.65 m and 45° for Case 1
- H2 at 0.63 m and 45° for Case 1
2) References


Licentiate thesis: http://urn.kb.se/resolve?urn=urn:nbn:se:kth:diva-196544
3) Boundary inverse heat conduction problem

- Find surface temperatures and radial heat flux ← literature
- 2D domain without any holes
- Transient case
- Ill-posed problem → Well-posed optimization problem
  Regularization
- Conjugate gradient method

1. Solve direct problem
2. Solve adjoint problem
3. Solve sensitivity problem
4. Repeat until convergence is reached

FEniCS
Mesh for the forward heat conduction problem

Mesh for the inverse heat conduction problem
3) Test problem - Error
3) Lab case

Right thermocouple disc

Aim: Find T and q in the blue circle and in the yellow annulus

T and q are known on the blue edge from measurements and interpolation → Direct heat conduction problem for the blue circle

T and q are unknown on the yellow edge → Inverse heat conduction problem for the yellow annulus
3) Lab case - Heat flux
3) Next steps

- Update the geometry
- Find the heat flux in the middle of the thermocouple disc
- Improve
  - conjugate gradient method
  - choice of the regularization parameter
- Finalize manuscript for publication
- Version for 3D geometries? If so, parallelization
4) Large eddy simulation of thermal mixing

- Roman Thiele’s work:
  [http://urn.kb.se/resolve?urn=urn:nbn:se:kth:di...](http://urn.kb.se/resolve?urn=urn:nbn:se:kth:di...)
- OpenFOAM (v4.1), open-source CFD software
- (Static) WALE model
- Conjugate heat transfer
- PIMPLE
- ICEM mesh
- $\Delta T = 216 \text{ K} \rightarrow 261 \text{ K}$
- Cooperation with André Tengstrand (Bo Alfredsson and Pål Efsing’s “Failure risk of NPP components due to LSY crack propagation in environment at transient thermal loads”)

"Failure risk of NPP components due to LSY crack propagation in environment at transient thermal loads"
4) Results – p and T at the inner tube
4) Results and next steps

Data saved:
- Temperature in the solid domains
- Pressure at the walls
- ...

Need for large allocation
E.g., 1024 cores
- 17.3e6 cells in the water domain
- 0.07 s of simulation time per day
→ Apply for large allocation by October 20th
Thank you for your attention!

Questions?

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1) Test section

<table>
<thead>
<tr>
<th>Description</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axial distance between hot and cold inlets</td>
<td>650 mm</td>
</tr>
<tr>
<td>Axial distance between hot inlets and outlets</td>
<td>200 mm</td>
</tr>
<tr>
<td>Diameter of the inlets</td>
<td>7.5 mm</td>
</tr>
<tr>
<td>Diameter of the outlets</td>
<td>14 mm</td>
</tr>
<tr>
<td>Outer diameter of the outer tube</td>
<td>100 mm</td>
</tr>
<tr>
<td>Inner diameter of the outer tube</td>
<td>80 mm</td>
</tr>
<tr>
<td>Outer diameter of the inner tube</td>
<td>35 mm</td>
</tr>
<tr>
<td>Inner diameter of the inner tube</td>
<td>25 mm</td>
</tr>
</tbody>
</table>
1) $T_{H2}$ for Case 1 at 225°

<table>
<thead>
<tr>
<th>Case</th>
<th>$\dot{m}_H$ (kg/s)</th>
<th>$\dot{m}_C$ (kg/s)</th>
<th>$T_H$ (°C)</th>
<th>$T_C$ (°C)</th>
<th>$p$ (bar)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.8</td>
<td>0.07</td>
<td>276</td>
<td>60</td>
<td>72</td>
</tr>
</tbody>
</table>

H2 at 0.67 m and 225°

H2 at 0.65 m and 225°

H2 at 0.63 m and 225°

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