AN EFFICIENT CFD MODEL FOR QUANTIFICATION OF HEAT OIL CARRY-OVER COEFFICIENTS IN GROOVES

Dr. Jing Yang
Post-Doctoral Research Associate

Rasool Koosha
Graduate Research Assistant

Dr. Luis San Andrés
Mast-Childs Chair Professor
Fluid film bearing analyses in XLTRC®

- 2D hydrodynamic pressure on pad surface.
  - Cross-film viscosity variation.
  - Accounts for turbulent flow effects.

- 3D temperature distribution in fluid film.
  - Heat conduction to the pads.
  - Accounts for turbulent flow effects.

- 3D temperature distribution in pad and liner.
  - Heat transfer boundary conditions on all sides of a pad.

- 3D elastic deformations in bearing pad.
  - Both temperature and pressure induced.

Yet, a too simplified model for thermal energy mixing at the oil feed groove, using hot oil carry-over coefficient ($\lambda$), an empirical parameter.
Conventional lubricant mixing in a feed groove

\[ Q_{sup} = Q_{LE} - \lambda Q_{TE} \]

\[ T_{LE} = \frac{Q_{sup} T_{sup} + (\lambda Q_{TE}) T_{LE}}{Q_{LE}} \]

\( \lambda \) is empirical.

- Required supply flow \( Q_{sup} \) based only on upstream flow \( Q_{TE} \) and downstream flow \( Q_{LE} \). (No oil churning considered)

- What if \( Q_{LE} < \lambda Q_{TE} \) ? \( \Rightarrow Q_{sup} = 0 ? \)

- During operation actual supply flow may differ from predicted (during design)

- In practice, \( Q_{sup} \) is controlled by available delivery system, rarely varying with operating condition.
Example Six-pad TPTB

- Configuration from Mikula 1986.

**Shaft rotational speed** $\Omega$  
7 krpm

**Max surface speed** $\Omega R_o$  
75 m/s

**Specific load per pad** $W/(A_p N_p)$  
3.0 MPa

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of pads, $N_p$</td>
<td>6</td>
</tr>
<tr>
<td>Outer/inner diameter</td>
<td>267/133 mm</td>
</tr>
<tr>
<td>Pad thickness</td>
<td>21.5 mm</td>
</tr>
<tr>
<td>Babbitt thickness</td>
<td>1.5 mm</td>
</tr>
<tr>
<td>Pad arc length</td>
<td>50°</td>
</tr>
<tr>
<td>Pivot offset</td>
<td>50 %</td>
</tr>
<tr>
<td>Pad material</td>
<td>Steel</td>
</tr>
<tr>
<td>Lubricant Inlet at 46 C</td>
<td>ISO VG32</td>
</tr>
</tbody>
</table>

**Take $\lambda$: 0.4 \rightarrow 0.95 from**

Influence of $\lambda$ on Min Film Thickness

Specific load/pad = 3.0 Mpa
Rotor speed = 7 krpm.

As $\lambda$ increases, 0.4 $\Rightarrow$ 0.95: $\Rightarrow$ minimum film thickness reduces by 23%.
Influence of $\lambda$ on Drag Power Loss

Specific load/pad = 3.0 Mpa
Rotor speed = 7 krpm.

As $\lambda$ increases, $0.4 \rightarrow 0.95$: $\Rightarrow$ drag power loss reduces by 25%.
Influence of $\lambda$ on Oil Flow

Specific load/pad = 3.0 Mpa, rotor speed = 7 krpm.

$\lambda \in 0.4 \rightarrow 0.95$: flow reduces by 50%.

Hot oil carry-over ($\lambda$) has substantial influence on bearing performance predictions.

Analysis needed to accurately quantify $\lambda$ for distinct operating conditions and bearing feed groove geometry.
A Novel Model from San Andres and Abdollahi

- Rectifying known limitations associated with the conventional hot oil carry over model:
  - explicit distinction between flooded or evacuated configurations.
  - distinct portions of supply flow (not equal) for each groove based on operating condition.
  - Works where the flow rate is specified or known and not the inlet pressure.

Abdollahi and San Andres, 2019, J. Tribol., 141.

Predictions show a significant improvement compared to those using the conventional hot oil carry-over model.
Flow balance at a feed port or groove

- **Sealed ends (FLOODED) bearing**, + lubricant is drawn from churning flow in groove.

  \[
  \text{if } \left( Q_{TE}^{i-1} + Q_{sup}^{i} \right) < Q_{LE}^{i} \rightarrow Q_{gr}^{i} = Q_{LE}^{i} - Q_{TE}^{i-1} - Q_{sup}^{i}
  \]

- **Open ends (EVACUATED) bearing**: Excess of supply flow leaves a port as a side leakage.

  \[
  \text{if } \left( Q_{TE}^{i-1} + Q_{sup}^{i} \right) > Q_{LE}^{i} \rightarrow Q_{SL}^{i} = Q_{TE}^{i-1} + Q_{sup}^{i} - Q_{LE}^{i}
  \]

Abdollahi and San Andres, 2019, J. Tribol., 141.
Recent Work

- Computational fluid dynamics (CFD) analyses model flow in oil feed groove & adjacent fluid films.
- For TPTB: Wodtke et al. [3] compare conventional lubrication analysis vs. CFD:
  - CFD delivers accurate predictions.
  - Computational time for CFD is still orders of magnitude larger.

CFD is not yet a tool for routine engineering tasks

Continue further development of earlier model (San Andres and Abdollahi) to characterize via CFD analysis the fluid flow in distinct feed groove geometries and coupled to the upstream and downstream thin film flow regions.

Tasks:

(a) Build CFD models for feed grooves with various depth and width, and set boundaries with fluid velocities and temperature obtained from the thrust bearing analysis tool.

(b) Obtain CFD solutions of flow & thermal fields → quantify both a mixing flow hot carry over coefficient (λ) and/or a feed groove efficiency parameter (Cg).

(c) Update the radial and thrust bearing predictive tools with the parameters found.
<table>
<thead>
<tr>
<th>Description</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Support for graduate student (20 h/week) × $2,400 ×12 months</td>
<td>$14,400</td>
</tr>
<tr>
<td>Support research associate (10 h/week) × $5,000 ×12 months</td>
<td>$15,000</td>
</tr>
<tr>
<td>Fringe benefits (2.5%) and medical insurance ($210&amp;734/month)</td>
<td>$5,064</td>
</tr>
<tr>
<td>Travel to (US) technical conference</td>
<td>$2,500</td>
</tr>
<tr>
<td>Tuition &amp; fees three semesters (50%)</td>
<td>$8,598</td>
</tr>
<tr>
<td>(* student began work on 2016 (exempt from engineering graduate fee)</td>
<td>Total:  $50,000</td>
</tr>
</tbody>
</table>

The outcome of the work will improve fluid film bearing analysis tools in XLTRC®
Questions?

Learn more at http://rotorlab.tamu.edu
The mixing for thermal energy:

SEALED ENDS

EVACUATED ENDS