Evaluating self-lubricating materials for large scale bearings functioning under seawater conditions

Van Autrève S., Ost W., Van Wittenberghe J. and De Baets P.
Application

- Civil engineering: moving parts
- Ships & deck applications
- Locks, gates, drawbridges
- Mooring systems
- Hydropower

What makes these applications special
- Water lubricated
- Small amplitude
- Small velocity
- Corrosive/underwater
- Permanent loading
Typical materials

Bulk polymer materials
- Cheap
- Low strength
- Low PV value

Bronze materials
- Base material + solid lubricant
- High strength
- Friction $\mu \approx 0.2$
- Use of lead (lead bronze / lubricant)
- Adhesive wear / fretting wear

Composite materials
- Fibres : increased strength
- Solid lubricant PTFE
- Friction $\mu \approx 0.1$
- PV limit
Large scale testing

SCALE DEPENDENT:

- Distribution of solid lubricant
- Contact pressure & distribution
  - Edge effect
  - Non-uniform pressure
- Behaviour of wear particles
- Effect of (small) stroke

Typical application: Ø 300 mm
Typical small scale test: Ø 8 mm
Test setup

- Radially loaded bearing
- Load introduced by carriage (8 wheels)
- Shaft of bearing: oscillating movement
- Side flanges + seals: water lubrication

- Measured signals
  - Friction torque
  - Bulk temperature countersurface
  - Vertical displacement of bearing (wear)

- Controlled
  - Drive piston displacement
  - Radial load
Test setup

<table>
<thead>
<tr>
<th></th>
<th>Max radial load: 1350 kN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radial load</td>
<td>1350 kN</td>
</tr>
<tr>
<td>Max bearing size</td>
<td>Ø 400 mm, Length 300 mm</td>
</tr>
<tr>
<td>Max rotation</td>
<td>+/-15°</td>
</tr>
<tr>
<td>Max torque</td>
<td>100 kNm</td>
</tr>
<tr>
<td>Configuration</td>
<td>Moving shaft</td>
</tr>
<tr>
<td></td>
<td>Moving bearing</td>
</tr>
</tbody>
</table>
Test setup
Specimens

Bearing material
Back-up ring

Countersurface
Temperature sensor
Calculation of the COF

Sliding

\[ \mu = \frac{F_F}{F_N} = \tan \alpha = \frac{1}{\sqrt{\frac{1}{\sin^2 \alpha} - 1}} \]

\[ \sin \alpha = \frac{R_L}{R_B} \frac{F_L}{F_P + F_L} \]

\[ \mu = \frac{1}{\sqrt{\left(\frac{R_b}{R_L}\right)^2 \left(\frac{F_P + F_L}{F_L}\right)^2} - 1} = \tan \alpha \]

\( R_L, R_b \): known geometrical values

Contact line at \( \theta = a \)

Hydraulic piston

Loadcell \( F_P \)

Loadcell \( F_L \)
Oscillating movement

At velocity reversal: 

\[ \theta = \pm \alpha \]

\[ -\alpha < \theta < \alpha \]

Shaft rotation during rolling:

\[ \varphi_{2\alpha} = 2\alpha \cdot \frac{(R_s - R_b)}{R_s} = 2\alpha \frac{\text{clearance}}{\text{diameter}} \]

\[ \varphi = \theta \cdot \frac{(R_s - R_b)}{R_s} \]

\[ \Delta y = (R_b - R_s) \cdot (1 - \cos \theta) \]

\[ \Delta x = (R_b - R_s) \cdot \sin \theta \]

Bearing clearance

\[ \theta: \text{position contact line} \]

\[ b=0 \]

\[ \theta \text{bs} \]

\[ R \text{RR} \]

\[ \theta \sin \text{RRs} \]

At velocity reversal: ROLLING
<table>
<thead>
<tr>
<th><strong>Materials and test conditions</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Normal load:</strong> 100 kN (compression)</td>
</tr>
<tr>
<td><strong>Contact Pressure:</strong> 2.8 MPa</td>
</tr>
<tr>
<td><strong>Velocity bearing:</strong> 10 mm/s</td>
</tr>
<tr>
<td><strong>Sliding stroke:</strong> 10 mm</td>
</tr>
<tr>
<td><strong>Friction material:</strong> Filament wound composite material&lt;br&gt;Polystyrene fibres&lt;br&gt;Phenolic resin and PTFE (solid lubricant)&lt;br&gt;→ Φ 300 mm x 120 mm</td>
</tr>
<tr>
<td><strong>Counterspecimen:</strong> Steel S355J2G3&lt;br&gt;→ surface roughness: 0.2 µm &lt; Rₐ &lt; 0.3 µm</td>
</tr>
<tr>
<td><strong>Bearing clearance:</strong> 1.1 mm</td>
</tr>
</tbody>
</table>
Test results

Normal force $F_N$

Drive piston displacement

Friction force $F_F$
Test results

Measured horizontal displacement
Calculated horizontal displacement
Force on loadarm $F_L$

Elastic deformation

Drive piston displacement

Displ. Drive piston [mm]

FL [kN],

Horizontal Displacement Bushing [mm]

Time [s]
Test results

Coefficient of friction

\( \mu_{\text{stat}} \approx 0.14 \)

\( \mu_{\text{dyn}} \approx 0.12 \)

Drive piston displacement

Tribology and Fatigue

Laboratory Soete
Test results

Coefficient of friction – shaft rotation

Clearance in loadcell connection
Conclusions

✔ Test apparatus developed for
  → Large scale testing (heavy loading conditions)
  → Evaluation of friction and wear behaviour of journal bearings
  → Dry and wet (seawater) operating conditions

✔ First tests show
  → COF can be calculated from the measured $F_P$ and $F_L$
  → Measured values of COF correspond to manufacturers values
  → Elastic deformation should be taken into account for the calculation of the rolling angle