Hydrodynamic Lubrication Analysis of Eccentric Bearing in Rotary Compressor

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Background

In order to improve an efficiency of a rotary compressor, it is necessary to reduce the friction loss of the sliding surfaces.
The friction loss of an eccentric bearing (consists of crank and roller) has highest percentage among the friction loss.

Friction loss of rotary compressor

- Main bearing
- Sub bearing
- Eccentric bearing
- Vane side
- Vane tip
- Thrust bearing
- Balance
- Others
Analysis of Normal Eccentric Bearing

- Bearing load

The bearing load $F_{en}$ is as follows:

$$F_{en} = \sqrt{F_{r\theta}^2 + F_{r\phi}^2}$$  \hspace{1cm} (1)

$$F_{r\theta} = F_g \cos\left(\frac{\theta - \alpha}{2}\right) + F_a \sin \theta + F_e \cos \theta - F_{vt} \cos \alpha - F_{vt} \sin \alpha - F_{ct} \cos \theta$$

$$F_{r\phi} = F_g \sin\left(\frac{\theta - \alpha}{2}\right) - F_a \cos \theta + F_e \sin \theta + F_{vt} \cos \alpha - F_{vt} \sin \alpha - F_{ct} \cos \theta$$

$$\eta_{eb} = \tan^{-1} \frac{F_{r\phi}}{F_{r\theta}}$$  \hspace{1cm} (2)

And the motion equation of the roller is shown as follows:

$$I_r \ddot{\omega}_r = M_{eb} - M_a - R_{ro} \cdot (F_{vt} + F_{ct})$$  \hspace{1cm} (3)
Analysis of Normal Eccentric Bearing

- Friction moment

\[ \Lambda = \frac{h_{\text{min,en}}}{[h_{\text{min}}]_{e_b}} = \frac{h_{\text{min,en}}}{\sqrt{R_{z_{eb1}}^2 + R_{z_{eb2}}^2}} \]

\[ M_{eb} = \begin{cases} 
\frac{2\pi\mu_{oeb}B_{eb}^2R_{eb}^3(\omega_s - \omega_r)}{C_{eb}\sqrt{1 - \varepsilon_{eb}^2}} - \frac{1}{2} F_{eb}C_{eb}\varepsilon_{eb} \sin(\delta_{eb} - \eta_{eb}) , & \Lambda \geq 1 \\
\mu_{eb}F_{eb}R_{eb}\cos(\delta_{eb} - \eta_{eb}) , & \Lambda < 1 
\end{cases} \]
Analysis of Normal Eccentric Bearing

- Numerical results

<table>
<thead>
<tr>
<th>Item</th>
<th>Values</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suction pressure, $P_s$</td>
<td>1.084</td>
<td>MPa</td>
</tr>
<tr>
<td>Discharge pressure, $P_d$</td>
<td>2.765</td>
<td>MPa</td>
</tr>
<tr>
<td>Rotating frequency, $f$</td>
<td>60</td>
<td>Hz</td>
</tr>
</tbody>
</table>

- The peak of the bearing load is about 1500N when the shaft angle is about 210°
Analysis of Normal Eccentric Bearing

- The minimum oil film thickness is about 2μm, the bearing is in mix lubrication condition because the Λ parameter is about 1.12
Analysis of Normal Eccentric Bearing

- it is found that the direction does not rotate but remain within a constant range (about from 275° to 40°).
Analysis of New Eccentric Bearing

Figure 9 Scheme of New eccentric bearing

\[
M_{eb} = \begin{cases} 
\frac{2\pi \mu_{eb} B_{eb} R_{eb}^3 (\alpha_s - \alpha_r)}{C_{eb} \sqrt{1 - \varepsilon_{eb}^2}} \left[ A(\beta 1 + 2\pi) - A(\beta 2) \right] - \frac{1}{2} F_{eb} C_{eb} \varepsilon_{eb} \sin(\delta_{eb} - \eta_{eb}) \quad , \quad \Lambda \geq 1 \\
\mu_{eb} F_{eb} R_{eb} \cos(\delta_{eb} - \eta_{eb}) \quad , \quad \Lambda < 1 
\end{cases}
\]

\[
A(\theta) = \tan^{-1} \left( \frac{1 - \varepsilon_{eb}}{1 + \varepsilon_{eb}} \times \tan \frac{\theta}{2} \right)
\]
Analysis of New Eccentric Bearing

- Numerical results

The area of the cut off frictional surface of model A is more than that of model B.

<table>
<thead>
<tr>
<th>Model</th>
<th>$\beta_1$</th>
<th>$\beta_2$</th>
<th>Cut off area ($\beta_2 - \beta_1$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>model A</td>
<td>$10^\circ$</td>
<td>$130^\circ$</td>
<td>$120^\circ$</td>
</tr>
<tr>
<td>model B</td>
<td>$60^\circ$</td>
<td>$140^\circ$</td>
<td>$80^\circ$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Model</th>
<th>Capacity</th>
<th>Power consumption</th>
<th>COP</th>
</tr>
</thead>
<tbody>
<tr>
<td>normal eccentric bearing</td>
<td>$100%$</td>
<td>$100%$</td>
<td>$100%$</td>
</tr>
<tr>
<td>model A</td>
<td>$100%$</td>
<td>$98.7%$</td>
<td>$101.2%$</td>
</tr>
<tr>
<td>model B</td>
<td>$100%$</td>
<td>$99%$</td>
<td>$101%$</td>
</tr>
</tbody>
</table>
Experiment Results

- The results show that the new models give better efficiency than that of a normal eccentric bearing.
- It is also found that the experimental results showed increase in coefficient of performance (COP) by 1% which correspond to the numerical results.

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<th>Capacity</th>
<th>Power consumption</th>
<th>COP</th>
</tr>
</thead>
<tbody>
<tr>
<td>normal eccentric bearing</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>model A</td>
<td>100.1%</td>
<td>98.8%</td>
<td>101.3%</td>
</tr>
<tr>
<td>model B</td>
<td>99.9%</td>
<td>98.9%</td>
<td>101%</td>
</tr>
</tbody>
</table>
Experiment Results

- Reliability test results

In addition, to confirm the reliability of an eccentric bearing with cut off frictional surface, we did the reliability test under heavy load condition.

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<td>1.15</td>
<td>MPa</td>
</tr>
<tr>
<td>Discharge pressure, $P_d$</td>
<td>4.25</td>
<td>MPa</td>
</tr>
<tr>
<td>Rotating frequency, $f$</td>
<td>60</td>
<td>Hz</td>
</tr>
</tbody>
</table>
Experiment Results

- After 500 hours test, wear took place in the crank of Model A. But it did not happen in model B especially after 1500 hours test.

![Figure 10 Model A (500 Hours under heavy load condition)](image1)

![Figure 11 Model B (1500 Hours under heavy load condition)](image2)
Experiment Results

- The minimum oil film thickness is about 1μm, the bearing is in boundary lubrication condition because the Λ parameter is about 0.56. And the direction remain within a constant range (about from 300° to 25°).
Experiment Results

- And the cut off frictional surface of model A came into the range, made the oil film pressure decreasing, the thickness thinner. But model B did not come into the range, so it was better.
Summary

- Numerical and experimental analyses show that the new models give better efficiency than that of a normal eccentric bearing. The experimental results showed increase in COP by 1%.

- In addition, to confirm the reliability of an eccentric bearing with cut off frictional surface, we did the reliability test under conditions of optimum shape.
Thank you