Reliability and Performance Improvements to a Hydrogen Recycle Compressor
Part II

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Hydrogen Recycle Compressor

- Ingersoll Rand MGGB barrel compressor
- HDS Hydrogen Recycle service

- 2,500 hp
- 1785 rpm
- Motor

6.5:1 ratio

5 stage compressor
11,600 rpm
History

- Compressor vibration protection system not connected to plant historian, only route data collected.

- History of sub-synchronous vibration, possibly due to
  - Surging
  - Locked oil seals
  - Fixed geometry bearings
Vibration Spectrum Prior to Modifications
Process Re-rate

- Compressor speed being increased from 11,600 to 12,500 rpm due to low gas mole weight.

- Increase in speed required a rotor study to evaluate effects.

- Oil seals to be upgraded to address sour oil consumption.
Total rotor weight= 454.04 lbs
Rotor length= 64.584 in
Bearing Span= 49.287
Static Bearing Loads
sta 7= 229.26 lbs
sta 39= 224.78 lbs
CG is 32.9 in from sta 1
Undamped Critical Speed Map

Operating Speed = 12,561 rpm

\[ K_{eq} = \sqrt{K^2 + (\alpha l)^2} \]
Existing Seal Design

- Original design had OEM cone style bushing seals

- These seals have a large radial face to act on and lock up, causing potential oil whirl problems
New Oil Seals

- Windback cut in ID of inner seal ring to reduce sour oil
- High pressure ring separated into 3 lands to reduce laminar effects.
# Comparison of oil seals

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Cone Seal</th>
<th>Wind-back Seal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sleeve OD (in)</td>
<td>5.25</td>
<td>4.5</td>
</tr>
<tr>
<td>Radial Clearance (in)</td>
<td>0.003-0.004</td>
<td>0.003-0.004</td>
</tr>
<tr>
<td>Number of lands</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Length of land (in)</td>
<td>1.125</td>
<td>0.25</td>
</tr>
<tr>
<td>Width of groove between lands (in)</td>
<td>N/A</td>
<td>0.0625</td>
</tr>
<tr>
<td>Total Axial Length (in)</td>
<td>1.125</td>
<td>0.875</td>
</tr>
<tr>
<td>Differential Pressure (psid)</td>
<td>450</td>
<td>450</td>
</tr>
<tr>
<td>Oil type</td>
<td>Iso 32</td>
<td>Iso 32</td>
</tr>
<tr>
<td>Lapped face OD (in)</td>
<td>6.125</td>
<td>5.25</td>
</tr>
<tr>
<td>Lapped face ID (in)</td>
<td>5.625</td>
<td>4.75</td>
</tr>
</tbody>
</table>
## Comparison of Seals – Rotordynamic Effects

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Original Cone Seal</th>
<th>Wind-back Seal</th>
<th>Difference (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calculated axial load (lbf)</td>
<td>2500</td>
<td>1700</td>
<td>32</td>
</tr>
<tr>
<td>Calculated radial load capacity (lbf)</td>
<td>375</td>
<td>255</td>
<td>32</td>
</tr>
<tr>
<td>$K_{xy}$ (lbf/in)</td>
<td>270,000</td>
<td>142,000</td>
<td>47</td>
</tr>
<tr>
<td>$C_{yy}$ (lbf/s-in)</td>
<td>415</td>
<td>230</td>
<td>-45</td>
</tr>
<tr>
<td>$K_{xy}/\omega C_{yy}$</td>
<td>0.49</td>
<td>0.46</td>
<td>6.3</td>
</tr>
</tbody>
</table>
Damped Mode Shape Plot

w/ original fixed pad brg, Cd=0.004
Mode 1

f= 5505.42 cpm
ld= -0.05
N= 11600 rpm
Calculated Stability with Existing Cone Seals

- New seals improve stability at higher speed, but not enough
- Bearing modifications required to improve further

<table>
<thead>
<tr>
<th></th>
<th>Speed</th>
<th>Min Clear</th>
<th>Max Clear</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original bearings, no oil seals</td>
<td>11,600</td>
<td>-0.008</td>
<td>-0.009</td>
</tr>
<tr>
<td>Original bearings, oil seals included</td>
<td>11,600</td>
<td>-0.050</td>
<td>-0.051</td>
</tr>
<tr>
<td>Original bearings, no oil seals</td>
<td>12,561</td>
<td>-0.019</td>
<td>-0.02</td>
</tr>
<tr>
<td>Original bearings, oil seals included</td>
<td>12,561</td>
<td>-0.164</td>
<td>-0.165</td>
</tr>
<tr>
<td>Original bearings, modified seals</td>
<td>12,561</td>
<td>-0.051</td>
<td>-0.051</td>
</tr>
</tbody>
</table>
New Tilt-Pad Bearing
Damped Mode Shape Plot

w/5 pad, LOP, Cd=0.004, m=0.27, modified windback seal

Mode 1

\[
f = 5263.8 \text{ cpm} \\
\text{ld} = 0.36 \\
N = 12561 \text{ rpm}
\]
New Seals and New Bearings

- Replacing seals and bearings greatly increases calculated stability

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<th>Min clear</th>
<th>Max Clear</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOP bearings, no oil seals</td>
<td>12,561</td>
<td>0.513</td>
<td>0.85</td>
</tr>
<tr>
<td>LOP bearings, oil seals included</td>
<td>12,561</td>
<td>0.153</td>
<td>0.373</td>
</tr>
<tr>
<td>LOP bearings, modified oil seals</td>
<td>12,561</td>
<td>0.366</td>
<td>0.76</td>
</tr>
</tbody>
</table>
Forced Response

- Replacing the fixed geometry bearings with tilting-pad style greatly improves the predicted stability, but it comes at a cost.

- The damping provided by the tilt-pad bearings is less than the fixed geometry bearings, which increases the synchronous response at the 1^{st} critical. However, displacement levels are still acceptable and worth the improvement in stability.
Forced Response
w/ original fixed pad brg, Cd=0.004 and oil seals
Station 40 - DE probe
Forced Response

w/ new brgs/seals, mid-span unbalance

Station 40 - DE probe
Vibration Spectrum after Modifications

1 - 735 HC.2 Compressor
735 HC.2 - COH COMP. O. B. Horiz

Overall = 0.4582 D-DG
P-P = 0.4566
Load = 100.0
RPM = 12575. (209.58 Hz)

Freq: 206.63
Order: 0.986
Spec: 0.354
Results

- Compressor was re-rated in record time with no vibration issues present. It has operated for 1.5 years without any problems.

- Examination of the spectrum after the modifications shows that the subsynchronous peak is still present, but significantly smaller in amplitude.