Root Cause Analysis of vibrations in a Roots Blower system

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Problem description

- A roots blower system is suffering from excessive vibrations
- A temporary work-around enabled the operation of the plant, at a large expense of additional power consumption
- The fundamental mechanism of the observed vibrations was insufficiently clear, and there was an urgent need for an effective solution strategy
Underground Gas Storage (UGS)

- Large new UGS infrastructure (2011, Central Europe, $2 \times 10^9 \text{ m}^3$ storage capacity)
- To ensure sufficient buffer capacity upon high demand, and for gas trading purposes
- Storage in depleted natural gas caverns
- Challenging application, requiring high availability of rotating equipment
Drying of the gas

- Stored gas contains excess liquid; before injection the gas must be dried
- Adsorbing technology using silica gel grains is adopted
- Requires regeneration, using recirculation loop with heaters and separators
- Roots blower is used to compensate for the additional pressure loss
Roots Blower

- Newly installed positive displacement machine
- ‘2D equivalent’ of screw compressor
- Low pressure ratio
- Variable speed
- Unsteady flow → gas pulsations
High vibrations on the piping

- Preliminary scan at site visit: vibration levels and spectral signature
- Unallowable levels (>> guideline from European Forum for Reciprocating Compressors)
- Evident relation with blower speed
- Side branches, liable to fatigue failure

<table>
<thead>
<tr>
<th>Part</th>
<th>Horizontal compressors [mm/s RMS]</th>
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<tbody>
<tr>
<td></td>
<td>Key zones</td>
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<tr>
<td></td>
<td>A/B</td>
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<tr>
<td>Foundation</td>
<td>2.00</td>
</tr>
<tr>
<td>Frame (top)</td>
<td>5.33</td>
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<tr>
<td>Cylinder (lateral)</td>
<td>8.67</td>
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<tr>
<td>Cylinder (rod)</td>
<td>10.67</td>
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<tr>
<td>Dampers</td>
<td>12.67</td>
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<tr>
<td>Piping</td>
<td>12.67</td>
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Preliminary conclusions

• Design philosophy did not consider **pulsating service**
  • Design is a copy of similar adsorber systems *without root blower*
  • No pulsation dampers
  • No restriction orifice plates
  • No ‘dynamic’ supporting layout
  • No alarm from roots blower vendor
• Temporary work-around; pressure loss for regeneration is compensated by downstream turbo-compressors
Proposed RCA and solution strategy

- Detailed pulsation and vibration measurements
- Numerical modelling and comparison with measurements
- Evaluation of the solutions with simulation models:
  - Solutions based on overall design for service with ‘positive displacement machinery’
  - Pulsation dampers
  - Orifice plates
- Numerical acoustic optimization
- Numerical mechanical optimization
Field survey

- Systematic scan over process conditions
- Low (33 bar) and high (55 bar) pressure
- Full speed range: 150-690 rpm
- Simultaneous recording of pulsations & vibrations
Field survey

- Unacceptable pulsation levels
- Strong resonances, $2^\text{nd}$ limits in API 618
- Unacceptable vibration levels
  - Strong resonances, up to 60 mm/s RMS, dominated by 4$^{\text{th}}$ and 8$^{\text{th}}$ order
- Tripping of the roots blower
- Effect of the *mechanical resonances* appears most prominent

Pulsations, *suction* and *discharge* side

Vibrations at suction side, 3 directions
Pulsation analysis

• Analysis with 1D pulsation model
• Generic model for blower pulses
• Matched with the measured pulsation levels
• Calculation of all configurations, full speed range
• Global trends in the simulations are comparable with the measured trends
Numerical optimization steps

- Pulsation dampers at inlet and outlet
- Restriction orifice plates
  - Significant suppression of acoustic resonances
  - Marginal negative effect on pulsation source strength, due to increased $\Delta p$ over blower
- Evaluate impact on pulsations and shaking forces
Simulation results

Forces on discharge piping: 1 (4\textsuperscript{th} harmonic)

Forces on roots blower: 1 (8\textsuperscript{th} harmonic)
Mechanical response analysis

• FEM model used for analysis (beam-type)
• Pulsation-induced shaking forces are applied to model
• Calculation of worst-case conditions
• Used to optimize supporting layout
Supporting layout

Measurement on pipe shoe

Support is loose, shall be improved
Implementation on site

- Pulsation dampers were designed and constructed within short time frame, (< 4 months)
- Orifice plates, bypass line modification and improved supporting
Verification of vibration levels

- Significant reduction on piping and roots blower
- No tripping of the roots blower
- Maximum vibration level is 20 mm/s
- Based on numerical analysis; no integrity issues
- At small bore side branches (on new pulsation dampers) some issues remain
Bracing of small branches not adequate

- Bracing must be stiff, compared to the branch
- In two directions
- Reduce length and/or overhung mass
Final layout

- Final verification on site
- Successful commissioning of gas drying facility, including the roots blower system
- Adequate performance over full scope of operation
Lessons learned

- Roots blowers are pulsation machines!
- A careful design can resolve the pulsation and vibration issues
- However, prevention is better than cure
- Reduction of pulsations by means of dampers and orifice plates is an effective control strategy
- To improve existing mechanical layout is challenging
- Not trivial to ensure adequate bracing
- Combination of measurements and numerical analysis powerful tool to identify and mitigate pulsations and vibrations