A Vibration Problem in Vertical Circulating Water Pumps

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Presented by:

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Vertical Circulating Water Pumps

- Two Pumps Operating in Parallel on Cooling Tower
- Single-Stage Mixed-Flow Type Pump
  - Semi-open Impeller Design
  - 77” Bowl Diameter / 54” Discharge
- Direct Drive with Induction Motor
  - 445 rpm (7.42 Hz)
  - 2,138 bhp
- Rated Condition:
  - 86,000 gpm
  - 86 feet
Vibration Amplitude

● **Factory Test**
  - Acceptance: ISO 10816-3, Group 3, Flexible Support Class, Zone B/C (0.28 in/s RMS)
    - Top of Motor (parallel-to-discharge): 0.22 in/s RMS
    - Top of Motor (perpendicular-to-discharge): 0.16 in/s RMS

● **Field Test**
  - Acceptance: ISO 10816-3, Group 3, Rigid Support Class, Zone B/C (0.18 in/s RMS)
    - Top of Motor (parallel-to-discharge): 0.13 in/s RMS
    - Top of Motor (perpendicular-to-discharge): 0.80 in/s RMS
    - Dominate frequency at 1X running speed.
Initial Field Vibration Spectrum
(perpendicular-to-discharge)

1x running speed vibration > 0.80 in/s
Design-Phase FEA Results

- Foundation flexibility – Based on concrete properties from Civil Engineering design
- Motor reed critical frequency – Based on motor vendor information (+/- 15% margin)

<table>
<thead>
<tr>
<th>Mode</th>
<th>Natural Frequency (Hz)</th>
<th>Separation Margin</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Parallel</td>
<td>4.70</td>
<td>-36.7%</td>
</tr>
<tr>
<td>1 Perpendicular</td>
<td>5.13</td>
<td>-30.8%</td>
</tr>
<tr>
<td>2 Parallel</td>
<td>8.32</td>
<td>12.1%</td>
</tr>
<tr>
<td>2 Perpendicular</td>
<td>8.73</td>
<td>17.7%</td>
</tr>
</tbody>
</table>

Running Speed = 7.42 Hz
Field Impact Test Conditions

- Pump installed per manufacturer’s recommendations
- Pump not running and forebay filled with water
  - Accounts for partial entrained water mass
- Motor coupled and rotor lift set
  - Weight of pump rotor is supported at motor thrust bearing
- Discharge piping connected with flexible expansion joint
Field Impact Test Results
(parallel-to-discharge)

6.88 Hz
(413 CPM)

10.25 Hz
(615 CPM)
Field Impact Test Results
(perpendicular-to-discharge)

7.75 Hz (465 CPM)
11.38 Hz (683 CPM)
Field No-Load Motor Test  
(uncoupled from pump)

- Traces indicate out-of-phase motion of top of motor compared to pump casing
- 1st pump bending mode
Field Natural Frequencies (semi-wet)

<table>
<thead>
<tr>
<th></th>
<th>Natural Frequency (Hz)</th>
<th>Separation Margin</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A Pump</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Direction</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parallel (1st Mode)</td>
<td>6.88</td>
<td>-7.3%</td>
</tr>
<tr>
<td>Perpendicular (1st Mode)</td>
<td>7.75</td>
<td>4.4%</td>
</tr>
<tr>
<td><strong>B Pump</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Direction</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parallel (1st Mode)</td>
<td>6.75</td>
<td>-9.0%</td>
</tr>
<tr>
<td>Perpendicular (1st Mode)</td>
<td>7.50</td>
<td>1.1%</td>
</tr>
</tbody>
</table>

Note: A pump vibrations were more than 5 times those on the B pump, indicating that the operating natural frequencies shift down by approximately 0.25 Hz.
Fixing the Problem

- **Finite Element Analysis**
  - Adjusted model to match field measurements, “Model Calibration”
    - Infinitely stiff foundation
    - Doubled motor reed critical frequency
  - Analyzed corrective action options with FEA to assure success

- **Cut Slots in Stiffening Ribs to De-Tune Natural Frequencies**
  - FEA predicted a minimum separation margin of 15% for the first mode (perpendicular)
  - Achieved as-measured separation margin of 12.4% first mode (perpendicular).
Modified Pump Impact Test Results
(parallel-to-discharge)

- 6.13 Hz (368 CPM)
- 9.75 Hz (585 CPM)
Modified Pump Impact Test Results  
(perpendicular-to-discharge)

6.50 Hz  
(390 CPM)

11.13 Hz  
(668 CPM)
# Final Natural Frequencies

Operational vibrations were 0.12 in/s RMS or less on both pumps in both directions and were acceptable.

<table>
<thead>
<tr>
<th>A Pump</th>
<th>Natural frequency (Hz)</th>
<th>% Change</th>
<th>% Separation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Direction</strong></td>
<td><strong>Before</strong></td>
<td><strong>After</strong></td>
<td></td>
</tr>
<tr>
<td>In Line (1st Mode)</td>
<td>6.88</td>
<td>6.13</td>
<td>10.90%</td>
</tr>
<tr>
<td>Perpendicular (1st Mode)</td>
<td>7.75</td>
<td>6.50</td>
<td>16.13%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>B Pump</th>
<th>Natural frequency (Hz)</th>
<th>% Change</th>
<th>% Separation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Direction</strong></td>
<td><strong>Before</strong></td>
<td><strong>After</strong></td>
<td></td>
</tr>
<tr>
<td>In Line (1st Mode)</td>
<td>6.75</td>
<td>6.13</td>
<td>9.19%</td>
</tr>
<tr>
<td>Perpendicular (1st Mode)</td>
<td>7.50</td>
<td>6.50</td>
<td>13.33%</td>
</tr>
</tbody>
</table>
Final Vibration Amplitudes

- Operational vibrations less than 0.12 in/s RMS on both pumps in all direction.
- Vibration meets acceptance standards.
- Pumps accepted by customer.
Conclusions

- Factory testing results cannot always ensure acceptable field vibration levels.
- FEA combined with field vibration measurements is an excellent tool for properly diagnosing and correcting unexpected field vibration problems.
- Without field vibration measurement, FEA is only as good as its input data assumptions
  - Foundation information
  - Motor reed critical frequency