Modification of BB1 pump vibration characteristics to meet ISO 13709 2nd edition (API 610 11th) limits

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## Summary of the pump in question #1

**API 610 designation BB1**

<table>
<thead>
<tr>
<th>Pump Service</th>
<th>Cooling water circulation (through cooling towers)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ruling Specification</td>
<td>API 610 8th edition</td>
</tr>
<tr>
<td>Impeller diameter D2</td>
<td>1073mm (42.25”) rated, 1219mm (48”) maximum</td>
</tr>
<tr>
<td>Running speed</td>
<td>514 RPM</td>
</tr>
<tr>
<td>Flow</td>
<td>8400 m³/hr (36985 USGPM) rated</td>
</tr>
<tr>
<td>Design Head</td>
<td>40m (131.2 ft)</td>
</tr>
<tr>
<td>Specific Speed</td>
<td>50 Metric (2600 US)</td>
</tr>
<tr>
<td>Suction Specific Speed</td>
<td>166 Metric (8550 US)</td>
</tr>
<tr>
<td>Casing Arrangement</td>
<td>Double volute, 180° opposed volute lips</td>
</tr>
<tr>
<td>Impeller Arrangement</td>
<td>6 vane double entry impeller, non staggered vanes</td>
</tr>
<tr>
<td>Bearing arrangement</td>
<td>Sleeve radial with dual oil rings, flooded tilting pad thrust bearing with shaft drive circulation system</td>
</tr>
</tbody>
</table>
Summary of the pump in question #2

Supplied by a different division of ITT

Factory tested September 2007

Commissioned ≈ 2008

Vibration problems seen at low flow (50 to 75% of rated) that were not seen during factory testing

Site vibration values exceeded API 610 allowable levels

Pump was shipped to our R&D facility for further evaluation
Test loop setup #1

- **Shop Air 100 psig** (valve normally closed)
- **Vacuum pump** (valve normally closed)
- **Tower**
- **Drain valve** (normally closed)
- **Backpressure valve**
- **Suction valve**
- **Discharge valve** (pressure breakdown)
- **Pump under test**
- **Pump drive via VFD & gearbox**
Test loop setup #2

- Gearbox
- Motor
- Pump
Initial testing results #1

Tested with “expected” site NPSHa of 13.4m (44ft), the pump met ISO 13709 (API 610) vibration criteria of 3.0 mm/s (0.12 in/s) in the preferred region (70 to 120% of rated) and 3.9 mm/s (0.156 in/s) elsewhere.

The customer requested testing to ISO 13709 2nd edition (API 610 11th) section 8.3.3.6, which requires testing at no more than 110% of rated NPSHa. The pump was retested at the rated NPSHa of 10m (33 ft) and vibration levels significantly exceeded the allowable vibration criteria.
Initial testing results #2

Waterfall
J-4302 B\OBV

Vane pass noise

OBV-Flow 6 51.5Hz .0440 in/sec
OBV-Flow 5 51.5Hz .0408 in/sec
OBV-Flow 4 51.5Hz .0567 in/sec
OBV-Flow 3 A 51.5Hz .0369 in/sec
OBV-Flow 3 B 51.5Hz .0209 in/sec
OBV-Flow 2 51.5Hz .0507 in/sec
OBV-Flow 1 51.5Hz .0875 in/sec

Broadband hydraulic noise
Analysis of contributors

1. Pump design circa 1970 intended for municipal water service (although successful used in ISO 13709 service on prior occasions)
   - 6 vane design, less than ideal with a 180° volute
   - Unstaggered vane design
   - Impeller eye larger than optimum by modern design rules
   - Suction casing area progression not optimum by modern design rules

2. Never previously required to meet ISO 13709 section 8.3.3.6 test

3. Large impeller trim

   \[\begin{array}{c}
   \text{Recirculation onset} \\
   \text{Shockless Flowrate}
   \end{array}\]

   \[\begin{array}{c}
   \text{Reduced flow range before recirculation}
   \end{array}\]

   \[\begin{array}{c}
   1219\text{mm (48")} \\
   1073\text{mm (42.25")}
   \end{array}\]
## Analysis of fixes

<table>
<thead>
<tr>
<th>Fix</th>
<th>Positives</th>
<th>Negatives</th>
<th>Vane pass vibration</th>
<th>Suct. side recirc.</th>
<th>Disch. side recirc</th>
<th>Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bull ring in the impeller ring eye</td>
<td>Will suppress suction side recirculation</td>
<td>Increases NPSHr at high flows</td>
<td>0</td>
<td>++</td>
<td>0</td>
<td>Yes</td>
</tr>
<tr>
<td>Profile ring with artificial “A” gap and bull ring incorporated</td>
<td>Will suppress suction side and discharge side recirculation</td>
<td>Long lead time</td>
<td>0</td>
<td>++</td>
<td>+++</td>
<td></td>
</tr>
<tr>
<td>Cutback top half casing volute lip to 168°</td>
<td>Will reduce vane pass vibration</td>
<td>Will increase radial thrust.</td>
<td>++</td>
<td>0</td>
<td>0</td>
<td>Yes</td>
</tr>
<tr>
<td>V cut both casing volute lips</td>
<td>Will reduce vane pass vibration</td>
<td>Reduction effect will not be as much as the 168° cutback</td>
<td>+</td>
<td>0</td>
<td>0</td>
<td>Yes</td>
</tr>
<tr>
<td>Alter the position of the suction casing stop piece</td>
<td>Can improve the uniformity of flow into impeller and suppress instability</td>
<td>Requires a CFD analysis for correct location. Only a small improvement expected</td>
<td>0</td>
<td>+</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Cast and machine and impeller with full diameter shrouds and trimmed vanes</td>
<td>Will suppress discharge side recirculation</td>
<td>Long lead time Cost</td>
<td>0</td>
<td>0</td>
<td>++</td>
<td></td>
</tr>
<tr>
<td>Design and manufacture a new 5/7 vane impeller with closer to full diameter</td>
<td>Improves all symptoms</td>
<td>Long lead time Cost</td>
<td>+++</td>
<td>++</td>
<td>++</td>
<td></td>
</tr>
</tbody>
</table>
Application of chosen Fixes #1

A suction side restriction ring (commonly known as a “Bull Ring”), was added to the casing.

The purpose of this ring is to limit suction side impeller recirculation.
Application of chosen Fixes #2

The top half casing volute lip was cutback to create an angle of 168° relative to the lower half volute lip.

The cutback was angled 30° to smear the pressure pulse in the time domain.

White marks indicate material removed.
Application of chosen Fixes #3

The bottom half casing volute lip was angled 30° to smear the pressure pulse in the time domain.
Testing results after modifications #1

Testing confirmed the effectiveness of the modifications at suppressing low flow vibration behavior, but created a problem at higher flows.

So what went wrong?

![Graph showing vibration levels before and after modifications at different % BEP flows. The graph compares vibration (in/s) and vibration (mm/s) at 10m (33ft) NPSHa with the ISO 13709 Limit. The graph indicates a decrease in vibration after modifications.]
Testing results after modifications #2

A review of the NPSHr results gave a clue

The bull ring was causing significant head loss at higher flows:

• Head loss = Broadband hydraulic noise = Extra vibration
How to fix a Bull Ring #1

We applied a little used variant of the bull ring, which we call the Sabini Ring.
Testing results after bull ring changes #1

Testing confirmed the effectiveness of the changes to the bull ring

Vibration was now well controlled over the whole flow range
Testing results after modifications #2

The NPSHr results also indicate the success of the final bull ring design.
Conclusions

1. ISO 13709 section 8.3.3.6 testing can cause problems in older pump designs

2. Modern designs with the following are preferred:
   • 5 or 7 vane impellers with 180° volutes
   • 6 vane impellers with 168° volutes
   • Impeller eye diameter minimized in relation the target Nss value

3. Avoid large impeller trims as these promote recirculation and give a false indication of the true BEP (shockless) flow

4. Slotted bull rings offer a superior balance of recirculation suppression vs. NPSHr increase compared to plain rings.

Thanks for your attention