Vibration Assessment Method and Engineering Applications to Small Bore Piping in Nuclear Power Plant

Fei Xue, Lei Lin, Wenxin Ti, Nianwen Lu

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- Piping Vibration Assessment Method and Engineering Applications to Small Bore Piping in Nuclear Power Plant
Introduction of SNPI
Structure of SNPI
Major Research Fields

Main Research Fields

- Aging and Life Study of Plant Component
- Equipment Manufacturing QC Surveillance
- Nuclear Safety Review and Surveillance
- Environment Impact Assessment
- NPP Site Selection and Evaluation
- Non-Destructive Evaluation (PSI/ISI)
- Plant I&C Engineering and Development
- Plant Thermal Engineering and Chemistry
- Plant Welding and Maintenance
Laboratory (Metallic Aging)

Aging Laboratory

- Raw Material Performance
- Material Fatigue Performance
- Material Corrosion Performance
- Material Erosion Performance

Examination Facility

Fatigue Crack Growth Measurement System
Plant Ageing and Life Study

- Metallic equipments, for example
  - RPV
  - SG
  - Primary loop pump
  - Pressurizer
  - RVI
  - ......

- Metallic pipes, for example
  - Primary loop pipe
  - Auxiliary pipe of Primary loop pipe
  - Main feedwater pipe
  - Small bore line
  - ......

- Aging mechanisms
  - Thermal Aging Embrittlement
  - Thermal Fatigue
  - Vibratory Fatigue
  - FAC (Flow Accelerated Corrosion)
  - Irradiation Embrittlement
  - SCC
  - ......

SNPI — Suzhou Nuclear Power Research Institute
Piping Vibration Assessment Method and Engineering Applications to Small Bore Piping in Nuclear Power Plant
**Project Background**

- **Vibratory Fatigue Phenomena:**
  - 1991, leak from two small branch tube socket welds in unit 2 of Safety Injection system in Belleville Nuclear Power Plant, which leads to concern of small bore pipe vibratory fatigue.
  - Small bore pipe vibratory fatigue cracks also found in other NPPs in the world.
  - Since 1993, more than 11 vibratory fatigue cracks were found in Daya Bay and LingAo Nuclear Power Plants.
Project Background

- Period safety review requirement
  - In the first 10 years safety review of Daya Bay Nuclear Power Plant, vibration assessment for small bore pipes was required as one of the ‘special project’.
  - 2004, vibration assessment for NI small bore pipes was performed.
  - 2005, SNPI began the vibration assessment for CI small bore pipes of Daya Bay, unit 1. (Finished)
  - 2006~2007, vibration assessment for CI small bore pipes of Daya Bay, unit 2 were finished.
Cause of small bore pipe vibratory fatigue

- **Failure mode** ---- Low stress, high cycle fatigue.
- **Excitation mode** ----
  - Pressure pulsation, cavitation, flashing caused by pump;
  - Socket welds ---- the geometry size, discontinuity, and residual stress;
  - Design error ---- Inappropriate supports lead to resonant of piping system;
Assessment criterion

- Vibration monitoring and assessment criterion:
  
  - ASME OM-S/G part 3-2000
    
    - VMG3: Evaluated by visual inspection
    
    - VMG2: Evaluated by peak velocity and displacement
    
    - VMG1: Evaluated by vibratory stress
  
  - EDF method (Sébastien Caillaud, Didier Briand, 2003)
    
    - Effective velocity assessment method
Peak Velocity criterion

- Peak velocity (Vp) assessment method – ASME OM part 3

\[ V_{allow} = \frac{\alpha C_1 C_4}{C_3 C_5} \frac{0.8 \sigma_{al}}{C_2 K_2} \]

- Screening value: Vps=12.7mm/s
- If Vt>12.7mm/s, the allowable peak velocity Vpa should be calculated using the above equation.
- If Vt>Vpa, the vibration stress should be tested and compared with the allowable stress.
- Monitoring program or modification measures been performed.
Effective velocity criterion

- Effective velocity (Ve) assessment method – EDF

\[ V_{\text{rms}} = \frac{C_1 C_4}{C_0 C_3} \times \frac{\lambda}{C_2 K_2} \times 0.8S_A (mm/s) \]

- Screening value: Ves = 12 mm/s
- If Vt > 12 mm/s, the allowable effective velocity Vea should be calculated using the above equation.
- If Vt > Vea, the vibration stress should be tested and compared with the allowable stress.
- Monitoring programme or modification measures been performed.
Application of velocity assessment method

- Assessment programme:
  → ASME OM Part 3
- Assessment criteria:
  → Effective velocity criteria
- Target:
  → Daya Bay Nuclear Power Plant, CI of unit 1
- Condition:
  → Performed during the operating time.
- Material:
  → Carbon steel; Stainless steel
Application of velocity assessment method

- Vibration testing system:
  - Wavebook 512 data acquisition system
  - B&W accelerators
  - TS7350 filter (Yangzhou Taisi)
  - Low noise cable
  - PCB charge amplifier
  - Analysis software: DasyLab5.6
Application of velocity assessment method
Signal Processing Module
### Evaluation results

**Table 1: Assessment procedure for 2100 small bore pipes**

<table>
<thead>
<tr>
<th>Project name</th>
<th>Pipe numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total number of small bore pipes</td>
<td>2100</td>
</tr>
<tr>
<td>Concerned pipes-by functional analysis</td>
<td>926</td>
</tr>
<tr>
<td>Pipes needing vibration measurement</td>
<td>326</td>
</tr>
<tr>
<td>Pipes having peak velocity over 12.7 mm/s</td>
<td>67</td>
</tr>
<tr>
<td>Pipes having effective velocity over 12 mm/s</td>
<td>15</td>
</tr>
<tr>
<td>Pipes having effective velocity over allowable value</td>
<td>8</td>
</tr>
</tbody>
</table>
## Evaluation results

### Table 2.8: Small bore pipes having effective velocities over allowable values

<table>
<thead>
<tr>
<th>Number Of Piping</th>
<th>Functional role</th>
<th>$V_{rms}$ (mm/s)</th>
<th>$V_{rms\ allow}$ (mm/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PIPE01</td>
<td>DRAIN-TO-LIQUID-WASTE-COLLECTION-SYSTEM</td>
<td>50.37</td>
<td>4.96</td>
</tr>
<tr>
<td>PIPE02</td>
<td>DRAIN-TO-LIQUID-WASTE-COLLECTION-SYSTEM</td>
<td>38.11</td>
<td>27.52</td>
</tr>
<tr>
<td>PIPE03</td>
<td>DRAIN-TO-LIQUID-WASTE-COLLECTION-SYSTEM</td>
<td>55.46</td>
<td>25.01</td>
</tr>
<tr>
<td>PIPE04</td>
<td>DRAIN-TO-LIQUID-WASTE-COLLECTION-SYSTEM</td>
<td>16.9</td>
<td>13.34</td>
</tr>
<tr>
<td>PIPE05</td>
<td>MAIN-STEAM-TO-FEED-WATER-PUMP-TURBINE</td>
<td>23.71</td>
<td>9.23</td>
</tr>
<tr>
<td>PIPE06</td>
<td>DRAIN-TO-TURBINE-BYPASS-SYSTEM</td>
<td>18.74</td>
<td>13.74</td>
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<tr>
<td>PIPE07</td>
<td>DRAIN-TO-TURBINE-BYPASS-SYSTEM</td>
<td>14.85</td>
<td>12.61</td>
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<tr>
<td>PIPE08</td>
<td>SITE-DISPLAY-AND-MAIN-CONTROL-RECORD</td>
<td>22.28</td>
<td>18.19</td>
</tr>
</tbody>
</table>

- 25% pipes have allowable effective velocities lower than the screening value (12mm/s)
Conclusion

- Peak velocity criterion is more conservative than effective velocity criterion.
- Considering the numerical integral error and stead state vibration condition, effective velocity is more representative than peak velocity for stead state vibration.
- Effective velocity criterion is not conservative for all pipes. Important pipes with high level vibration may be missed during the screening process.
Future Work

- Dynamic stress measurement and assessment;
- Piping vibration mitigation measures research and practice;
- Coupled multi-physics analysis considering FSI and thermal stress;
- Technical supports on establishing piping vibration assessment standard for Chinese Nuclear Power Plants;
Thanks for Your Attention ！