Acoustic-Induced Vibration (AIV) Screening and Mitigation in Piping Systems

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About AIV

- Acoustically-Induced Vibation (AIV) refers to high-frequency broadband excitation and high-frequency vibration (typically 100-3000 Hz) in piping downstream of a pressure-reducing device (e.g., a control valve or pressure relief valve)
- Can result in high-cycle fatigue failures at branch connections or welded supports
- First identified in 1983 by Carucci and Mueller
- Often a concern in flare/blowdown piping with thin walls and large diameters

Image Courtesy Chemical & Process Technology

API Standard 521 (Sixth Edition)

- Screening for AIV is necessary to evaluate branch connection
  - "The Potential for acoustic fatique **should be evaluated** to identify potential high-risk welded pipe connections so that appropriate modifications can be made."
  - **"Systems identified as a risk using these evaluation methods should be mitigated."**
  - **"A sound power level greater than 155 dB should be further evaluated…"**

Based on the Carucci and Mueller design curve [49], a sound power less than or equal to 155 dB should not create any fatigue concern. A sound power level greater than 155 dB should be further evaluated using methods such as in Bibliographic Items [49] and [56] or a finite element modeling approach. Systems still identified as a risk using these evaluation methods should be mitigated (see 5.5.12.3).

5.5.12.3 Mitigation Options

Common examples of mitigation options when the sound power level is determined to be excessive include, but are not limited to, the following.

a) Reducing the mass flow rate and/or pressure drop across a valve.

b) Selecting depressuring and control valves with low noise trims.

c) Using thicker walled piping (i.e. lower *D*/*t*).

d) Improving the connection integrity by minimizing pipe fittings and attachments that produce high stress concentrations at the connection. Peak fatigue stress is lower in fittings and attachments with completely symmetric connections (e.g. reducing tees, full-wrap encirclements). Examples of design strategies to minimize stress include the following.

1) Removing the small-bore connection (e.g. hydrostatic vent or low point drain) or relocating to piping segments determined not to be at risk for acoustic induced vibration fatigue failure.

2) Making branch connections with fittings that ensure a smooth transition from branch to main line. Options to achieve this include reducing tees (which introduce no asymmetric discontinuities) and sweepolets or equivalent (which are asymmetric but with a smooth transition). Common branch connection techniques such as fabricated branch connection (stub-in, stub-on, etc.) are acceptable in piping at risk of acoustic induced vibration risk only if they are installed with full encirclement reinforcement band or sleeve on the main-line pipe. Weldolets and forged couplings should be avoided unless similarly reinforced. Use a forged or wrought tee fitting to execute the branch connection if available. Where a reducing tee is not available due to the relative sizes of the branch and run pipes, piping reducers ("swages") can be used to make the transition from small branch pipe to an available reducing tee. In this way, stress concentration due to asymmetric discontinuities in the piping can be avoided.

3) Ensuring that a header seam does not cross the connection weld line.

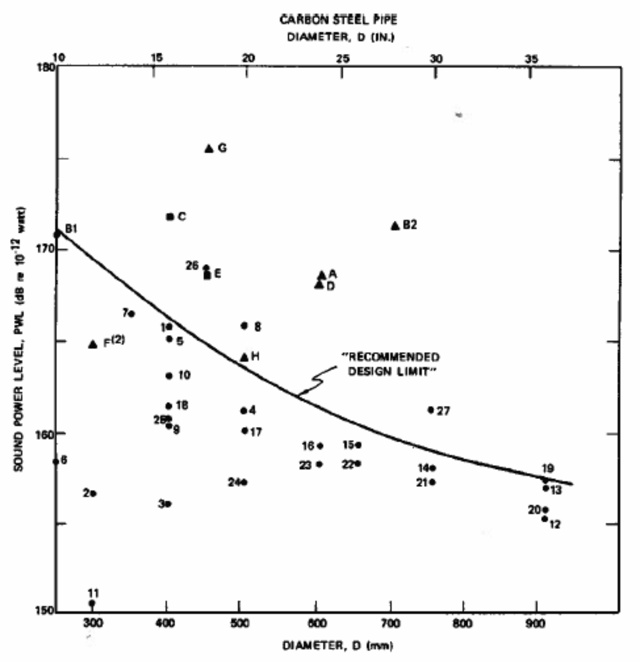
4) If fabricated branch connections (e.g. stub-in, stub-on, etc.) are unavoidable, use a 90° insertion angle instead of a 45° angle (with, for example, a "laterolet" or "elbowlet") as these have a better fatigue performance for acoustic excitation. It is noted that the use of a 45° lateral will improve the flow regime and reduce the low-frequency, flow induced vibration. However, this advantage of the 45° connection is negated in piping at risk of acoustic induced vibration by the difficulty in the weld penetration at the internal angle.

5) Avoid the use of stub-in or stub-on tees on connections of DN 50 mm (2 in.) or below. Instead, small-bore connections should be made to DN 100 mm (4 in.) or larger branches, which are then tied into the main (i.e. large diameter) subheader or header pipe.

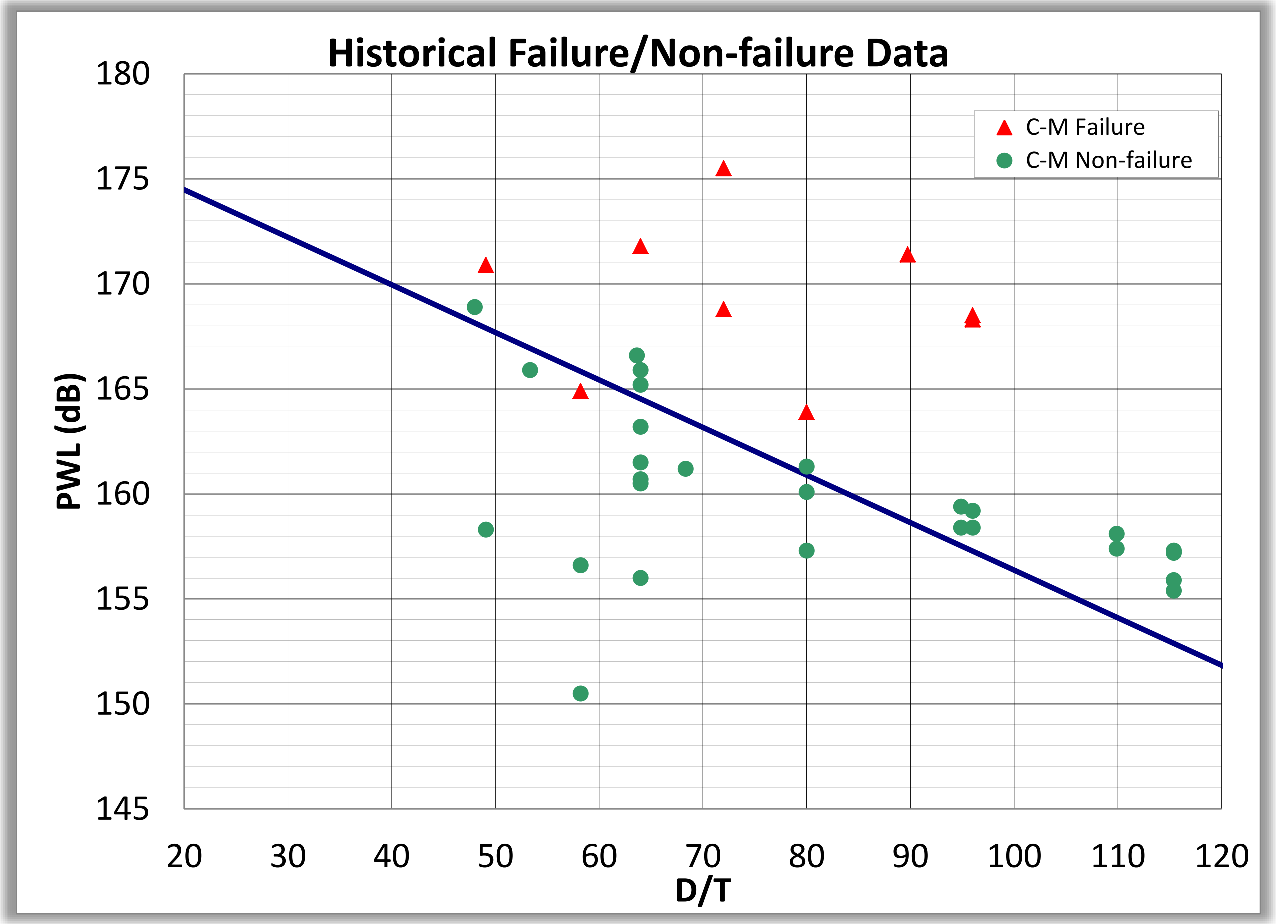
6) Avoiding intrusive fittings (e.g. thermowells).

Existing AIV Screening Methods

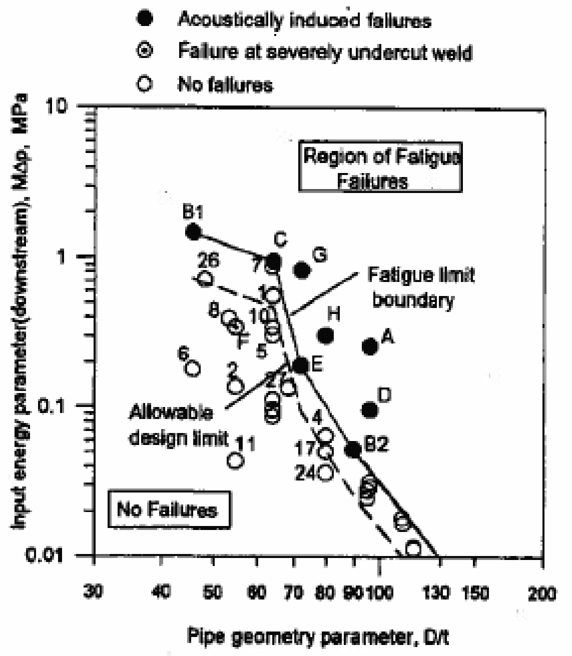
- Carucci-Mueller Design Curve



- Modified Carucci-Mueller and Eisinger Design Curve



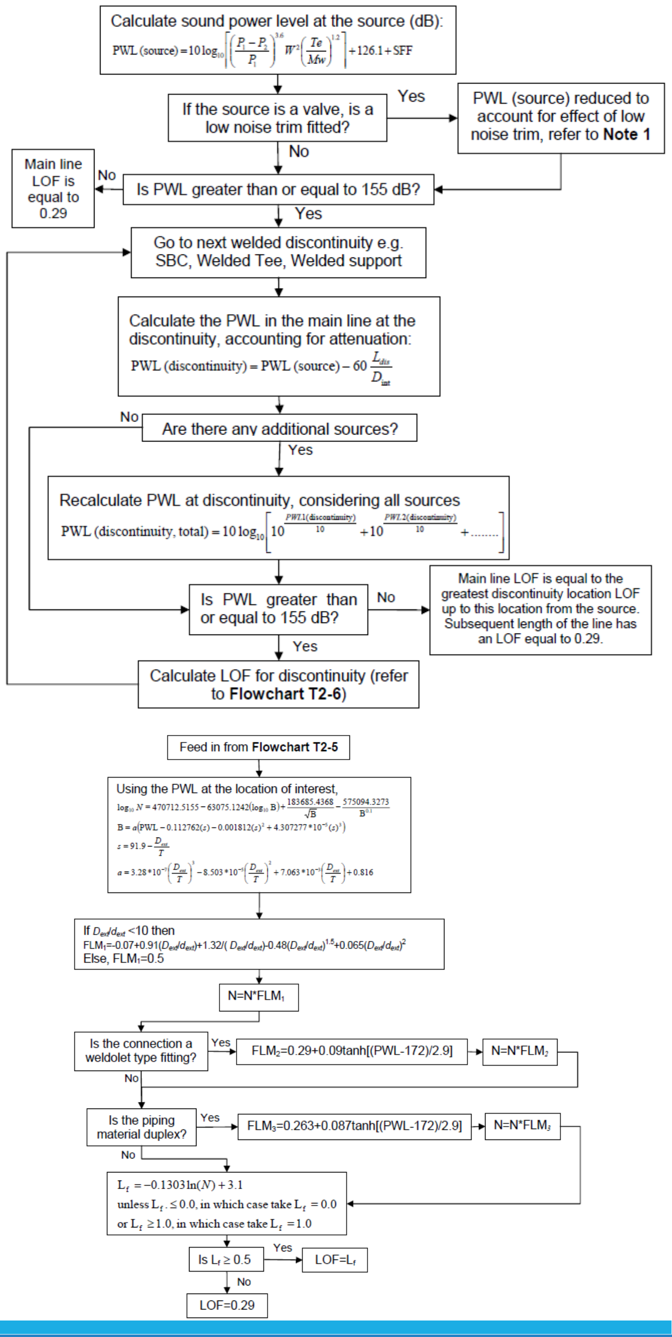
- Eisinger Design Curve



Evans, Allison, and Arnett 2012

Existing AIV Screening Methods

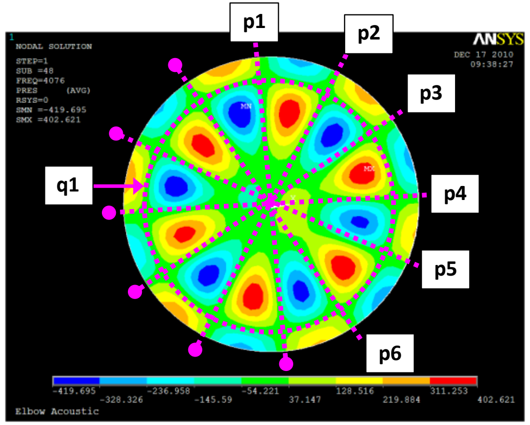
- The Energy Institute (2005) introduced a screening methodology* for AIV:
  - Simple source PWL computation
  - PWL decay to branch connection and addition of PWL from multiple sources at each branch
  - Estimate of fatigue life from curve-fit data (data from FE models calibrated to historical failure/non-failure data)
  - Fatigue life estimation including reduction due to weldolet fittings and small branch diameter to main line diameter ratios
  - Likelihood of Failure (LOF) computed from estimated fatigue life

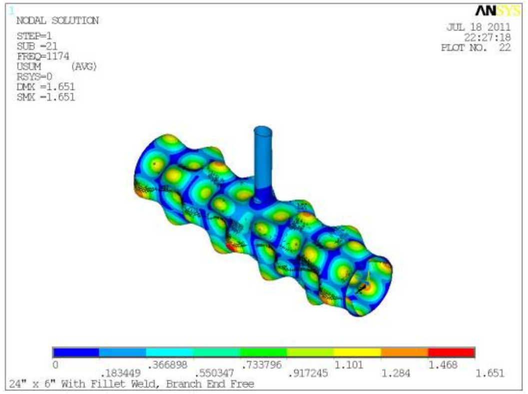


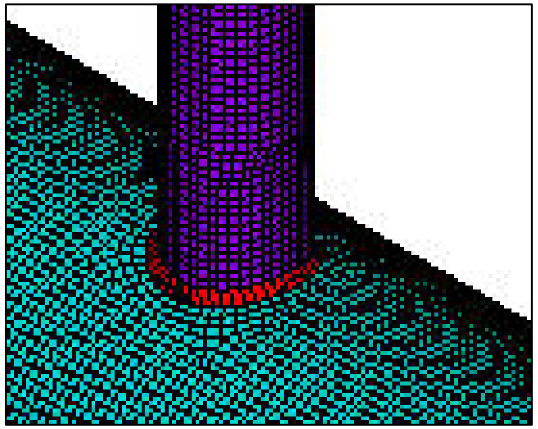
*See “Guidelines for the avoidance of vibration induced fatigue failure in process pipework,” Energy Institute, 2nd Ed., Jan 2008

Detailed Analysis Methods

- Determine coincidence of acoustic and pipe shell modes
  - Valve excitation analysis (Standard IEC 60534-8-3)
  - Acoustic analysis
  - Finite element analysis
- Forced response analysis of FE model at coincident modes performed with shell models to determine stresses at fillet weld and resulting fatigue life
  - Excitation from valve amplified by acoustic amplification factor to account for acoustic resonance
  - Stresses evaluated using mesh-insensitive procedure for welded joints in accordance with Section 5.5.5 of the ASME Boiler and Pressure Vessel Code, Section VIII, Division 2
  - Implementation of stress intensifier with the EI Guideline

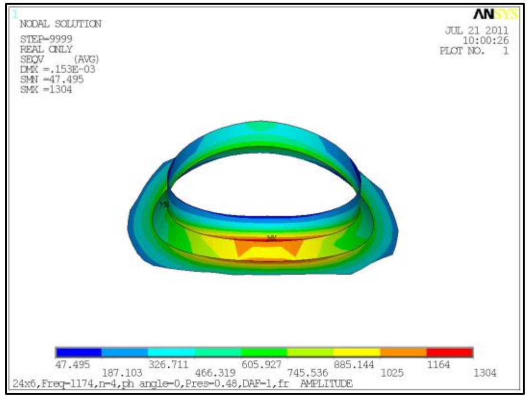


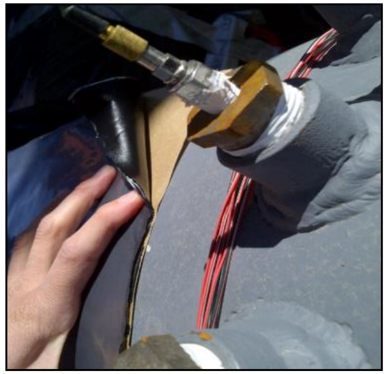


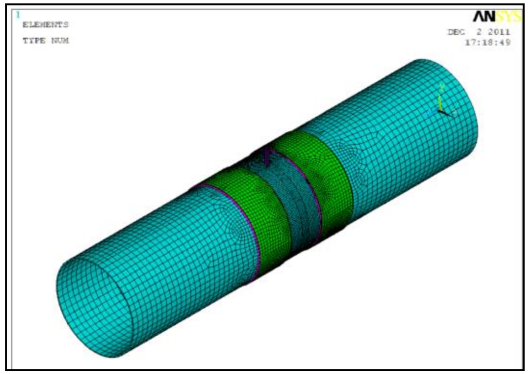


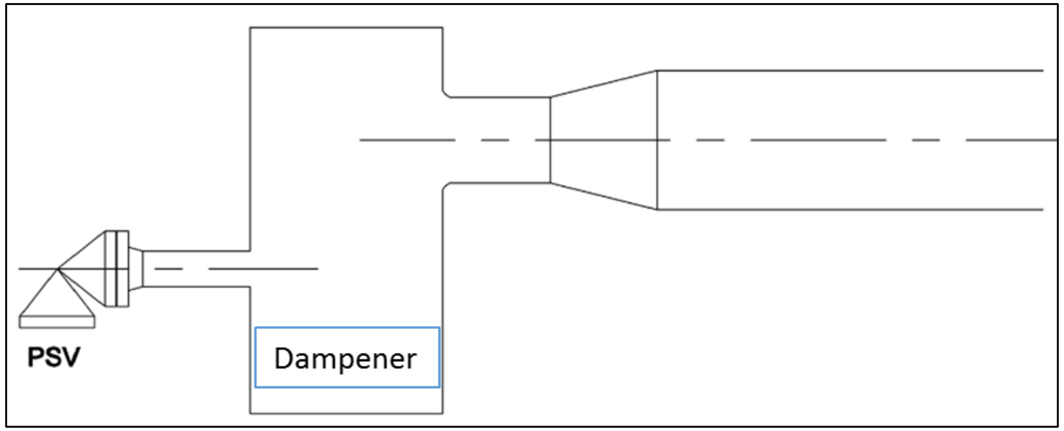
Tested AIV Solutions

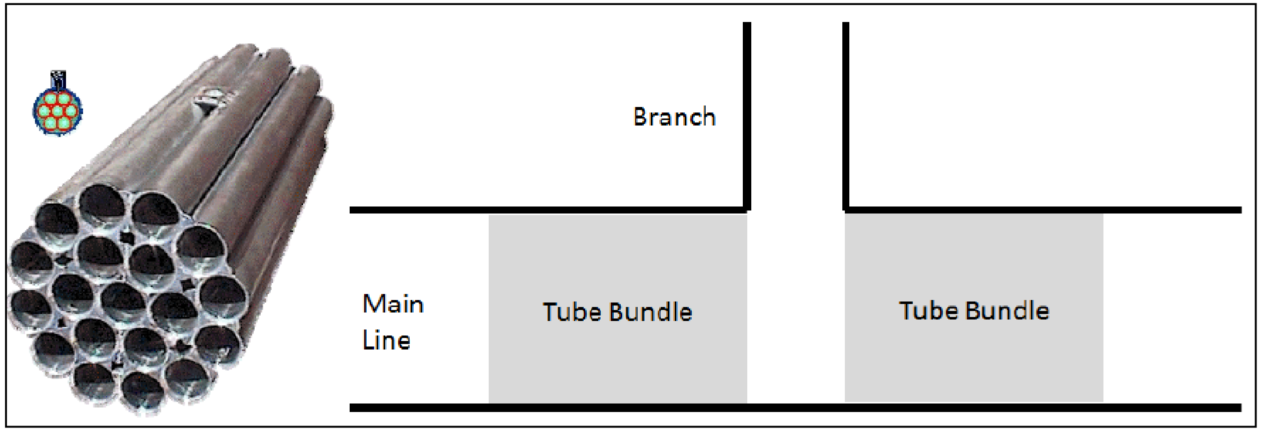
- Branch spacing and PWL attenuation
- Pipe connection and branch fitting type changes
- Reinforcement
- Stiffener rings
- Damping
- Tube Bundles











Testing of AIV Solutions at SwRI

- Continuous testing of multiple header geometries and AIV solutions

Test	Configuration	% reduction
1a	36" baseline	-
1b	36" clamps	51.8%
1c	36" damping wrap	11.1%
1d	36" tube bundles	30.1%
2a	20" baseline	-
2b	20" clamps	17.8%
2c	20" damping wrap	17.0%
2d	20" tube bundles	28.2%
3a	12" baseline	-
3b	12" clamps	15.8%
3c	12" damping wrap	8.4%
3d	12" tube bundles	*

*Based on SwRI 170 dB Nitrogen blowdown tests

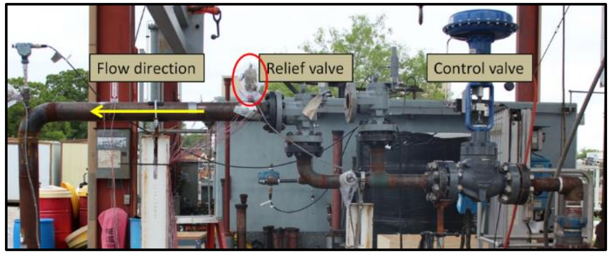
Continued SwRI AIV Testing

REDUCED-POWER TESTING

- Moderate Pressure: 100 psia
- High Flow rate of air: 6 lbm/s
- Manual or pneumatically actuated-controlled valves or orifices to create noise source
- Long duration tests

FULL-POWER TESTING

- Full blowdown tests to re-create a full power AIV excitation event using relief valves
- Pressure differentials of ~1600 psig
- Short duration flowrates (30 s) of 85 mmscfd
- Can reach sound power levels (PWL) of 175 dB



Analysis Method Comparison

	Carucci-Mueller	Eisinger	SwRI Modified C-M	Energy Institute	SwRI Finite Element
Calculates PWL	X		X	X	X
Includes pipe diameter	X	X	X	X	X
Uses historical data	X	X	X	X	See (1)
Includes pipe wall thickness		X	X	X	X
Includes multiple sources & decay		X	X	X	X
Includes connection type				X	X
Includes branch diameter				X	X
Includes acoustic/structural coincidence					X
Includes excitation frequency					X
Allows detailed analysis of design alternatives					X
Fatigue life calculation					X

[1]FEA methods must be calibrated with test and historical data

AIV Screening and Mitigation Analysis

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