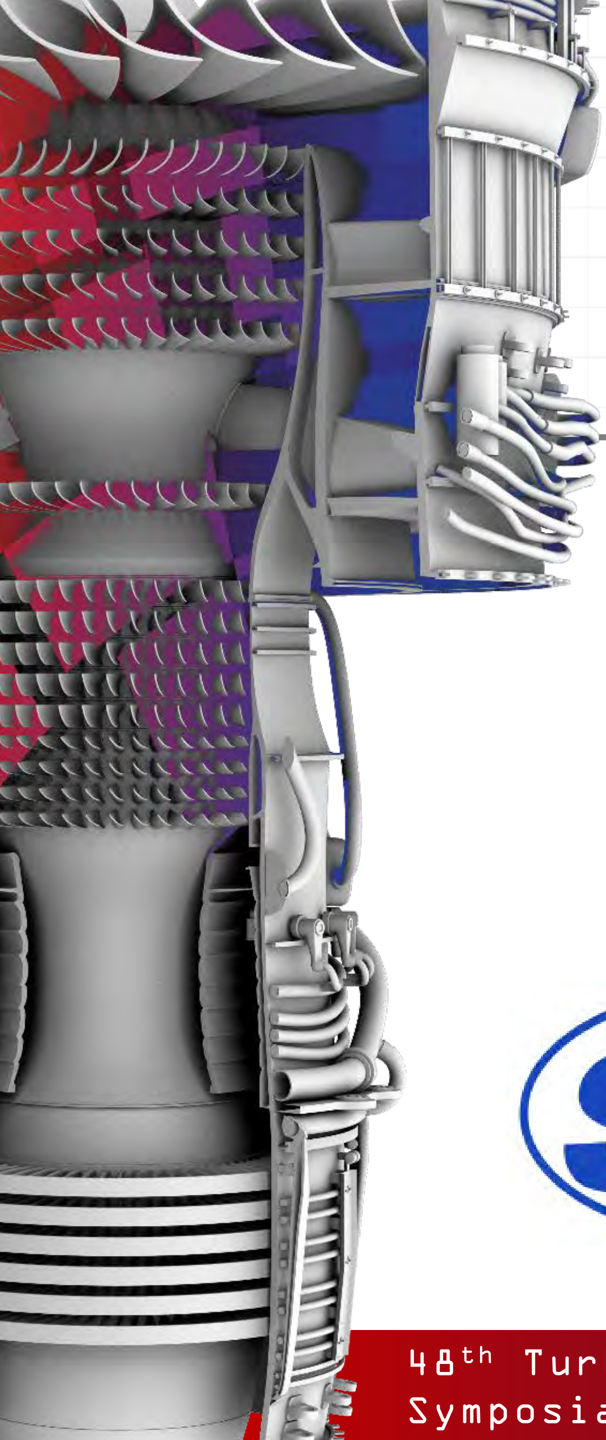


TURBOMACHINERY
& PUMP SYMPOSIA

Chandlersville and St. Paul: Unique Piping Vibration Issue in a New Centrifugal Compressor Installation

Eugene “Buddy” L. Broerman, III – SwRI
Robert Smith – Tallgrass Energy
Sarah Simons – SwRI
Benjamin A. White, P.E. – SwRI

Biographies

- **Eugene "Buddy" L. Broerman, III** is a Principal Engineer in the Fluid Machinery Systems Section at Southwest Research Institute (SwRI) in San Antonio, TX. He is a 2001 graduate of Texas A&M University-Kingsville with a B.S. degree in Mechanical Engineering. He has over 17 years of experience in the fields of mechanical vibrations, compressor and piping system design, acoustics, finite element analysis, and thermal piping stress.
- **Robert D. Smith** is currently the Sr. Compression Engineer in the Engineering and Tech Services Department with Tallgrass Energy, Lakewood, Colo. He has 39 years of experience in gas compression including installation, manufacturing with extended service/operations experience. He holds a BS in General Engineering from Kennedy-Western University and a 2-year certificate from Lamar University, Beaumont, TX.
- **Sarah Simons** is a Research Scientist in the Fluids Machinery Systems Section at SwRI. She has acquired experience in: performing thermal and acoustic analyses of compressor and pump piping systems as well as solving flow and acoustic problems in various types of piping; leading testing efforts in developing mixed compression analysis to determine the effect of pulsating flow on the surge margins of centrifugal compressors, equation-of-state property testing, performance testing for wet-gas in reciprocating compressor systems, and centrifugal compressor surge-force predictions.
- **Benjamin A. White, P.E.**, is currently the Manager for the Fluid Machinery Systems Section at Southwest Research Institute (SwRI) in San Antonio, TX. He is a 1995 graduate of Texas A&M University with a B.S. degree in Mechanical Engineering. He has over 20 years of experience in the fields of mechanical vibrations, compressor and piping system design, finite element analysis, thermal piping stress and acoustics.

Topics to Cover

- Problem: Description of the systems and problems
    - Chandlersville and St. Paul – 3 Centrifugal Compressors in parallel
    - Vortex-Shedding System-Wide Vibrations problem

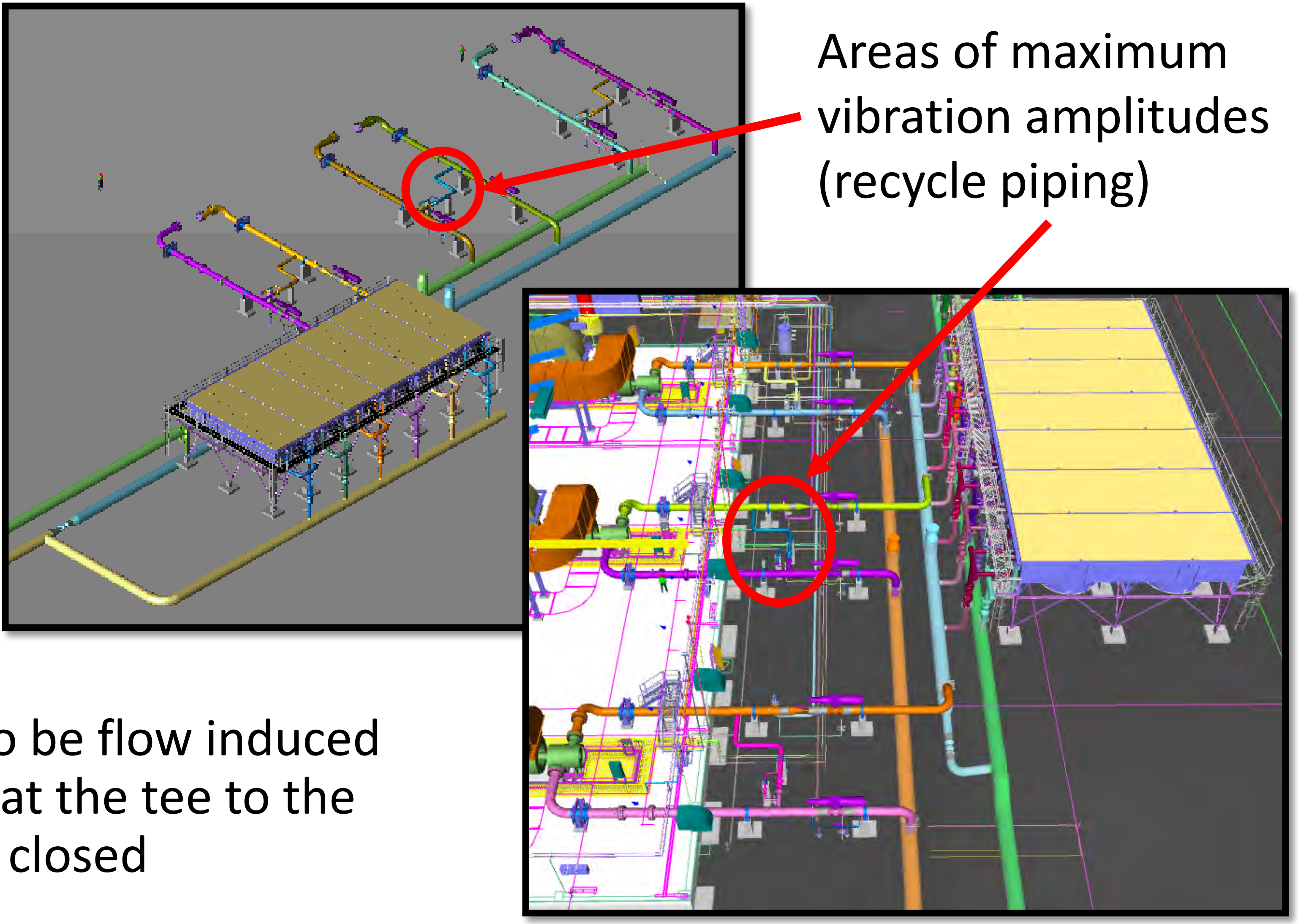
- Solutions:
    - Methods utilized to analyze the problem
    - Resulting solutions that were implemented

- Lessons Learned

This presentation was adapted from a 2018 GMC presentation.

Problem: Vortex-Shedding System-Wide Vibrations

- Description – any possible combination of 3 centrifugal compressors running in parallel
- Operators observed excessive vibration after startup
- Two similar stations experienced similar issues
- Vibration was worse with certain units running (the middle compressor)
- Pulsation and vibration data was measured in the field
- The root cause was determined to be flow induced pulsation due to vortex shedding at the tee to the recycle piping when recycle valve closed



Areas of maximum vibration amplitudes (recycle piping)

Field Testing Performed to Evaluate the System Problems

Compressor Surge

On Load

NGP 97.0 %

NPT 87.7 %

T5 1317 °F

3/1/2017
8:57:41 AM

[redacted]

0

Anti-Surge Control

ASC Setpoint 27.3 %

ASC Control Mode Auto

Anti-Surge Valve

ASC Valve Manual SP 100.0 %CL

ASC Valve Command 100.0 %CL

ASC Valve Position 99.9 %CL

Anti-Surge Parameters

Flow % 57.2 %

Head % 49.9 %

Turndown 53.7 %

Compressor Inputs

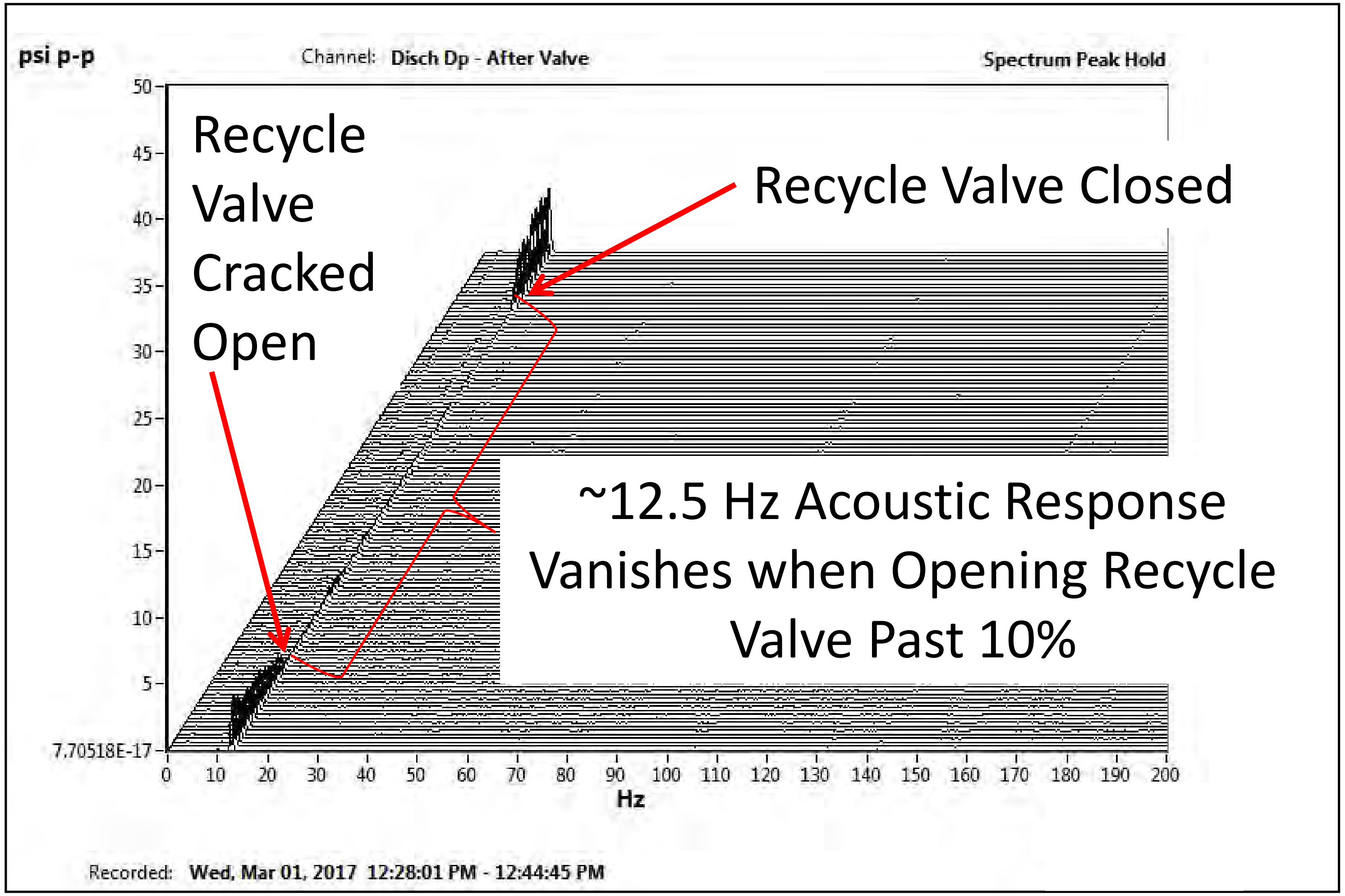
Suction 70 °F 710 psig

Discharge 119 °F 977 psig

Flow Meter DP 530 "H2O

Example Test Conditions:

- Suction: 710 psig, 70 F
- Discharge: 977 psig, 119 F
- All units nominally operating at 97% turbine speed



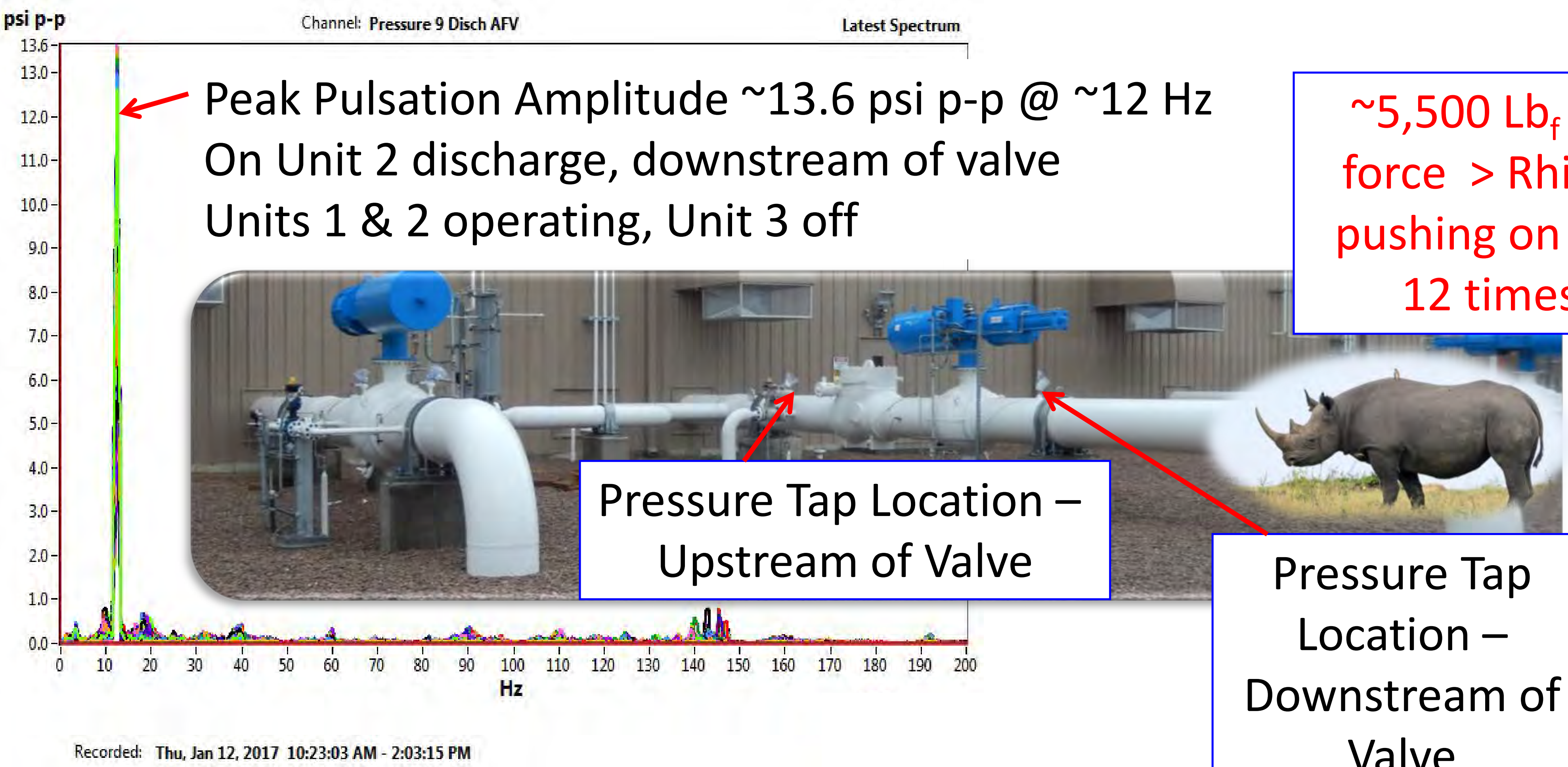
Recycle Valve Cracked Open

Recycle Valve Closed

~12.5 Hz Acoustic Response Vanishes when Opening Recycle Valve Past 10%

Pulsation Measured Downstream of Discharge Valve

Peak Pulsation Amplitude Measured: Unit 2 Discharge – Downstream of Valve



Peak Pulsation Amplitude ~13.6 psi p-p @ ~12 Hz
On Unit 2 discharge, downstream of valve
Units 1 & 2 operating, Unit 3 off

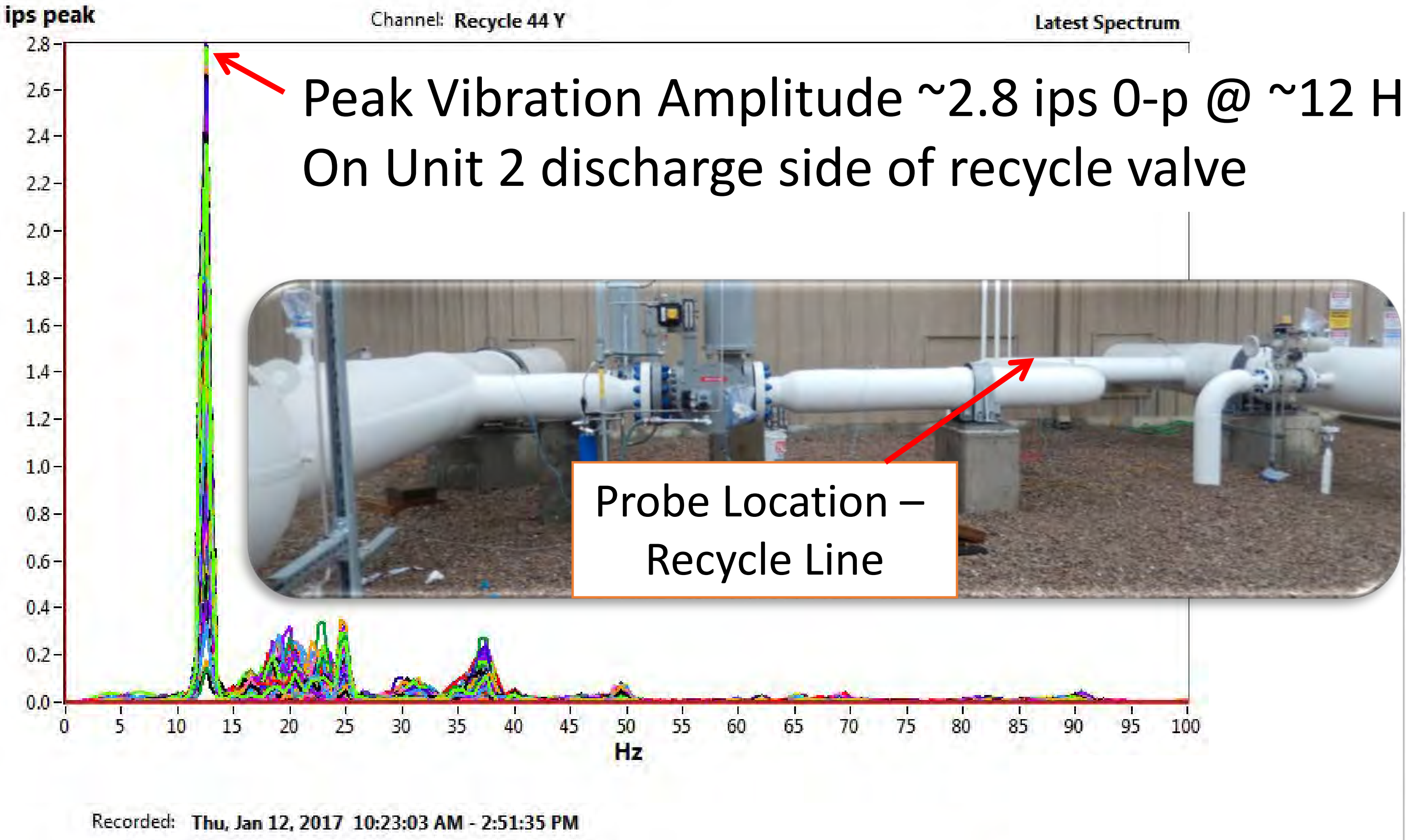
~5,500 Lb_f shaking force > Rhinoceros pushing on the pipe 12 times/sec.

Pressure Tap Location – Upstream of Valve

Pressure Tap Location – Downstream of Valve

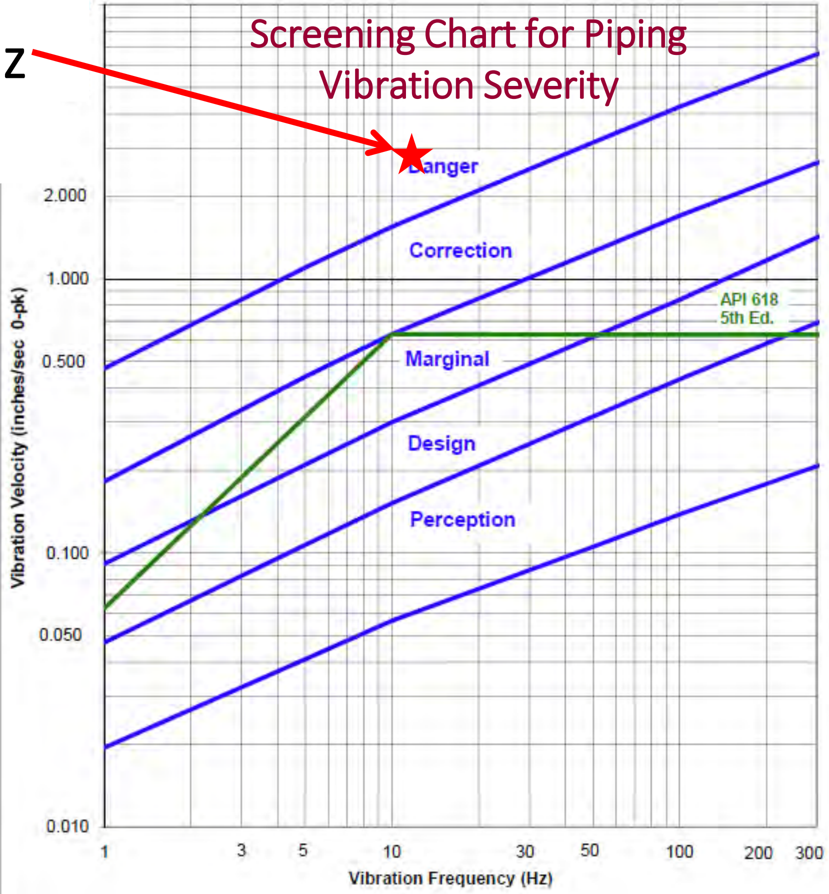
Recorded: Thu, Jan 12, 2017 10:23:03 AM - 2:03:15 PM

Peak Vibration Amplitude Measured: 2.8 ips 0-Pk on Unit 2 Recycle Line

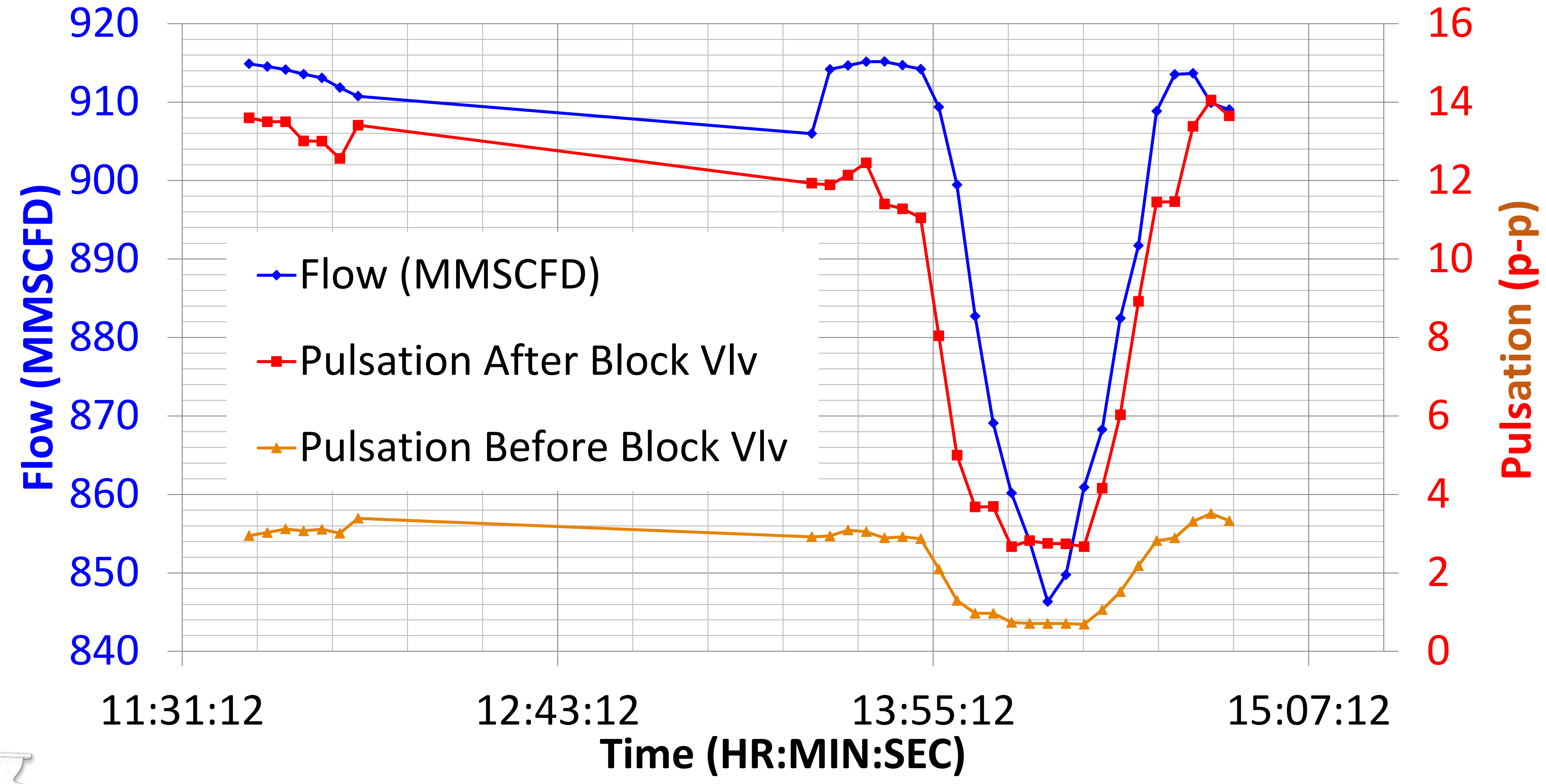


Peak Vibration Amplitude ~2.8 ips 0-p @ ~12 Hz
On Unit 2 discharge side of recycle valve

Probe Location – Recycle Line

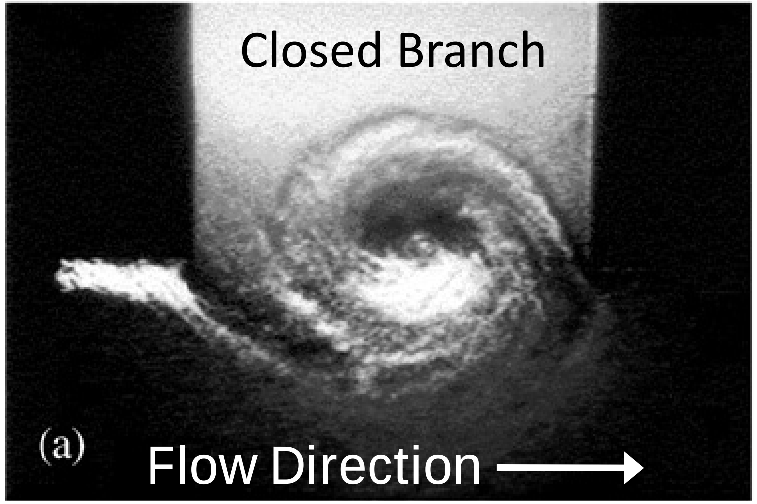

Screening Chart for Piping Vibration Severity

Pulsation Amplitude Tracks with Flow

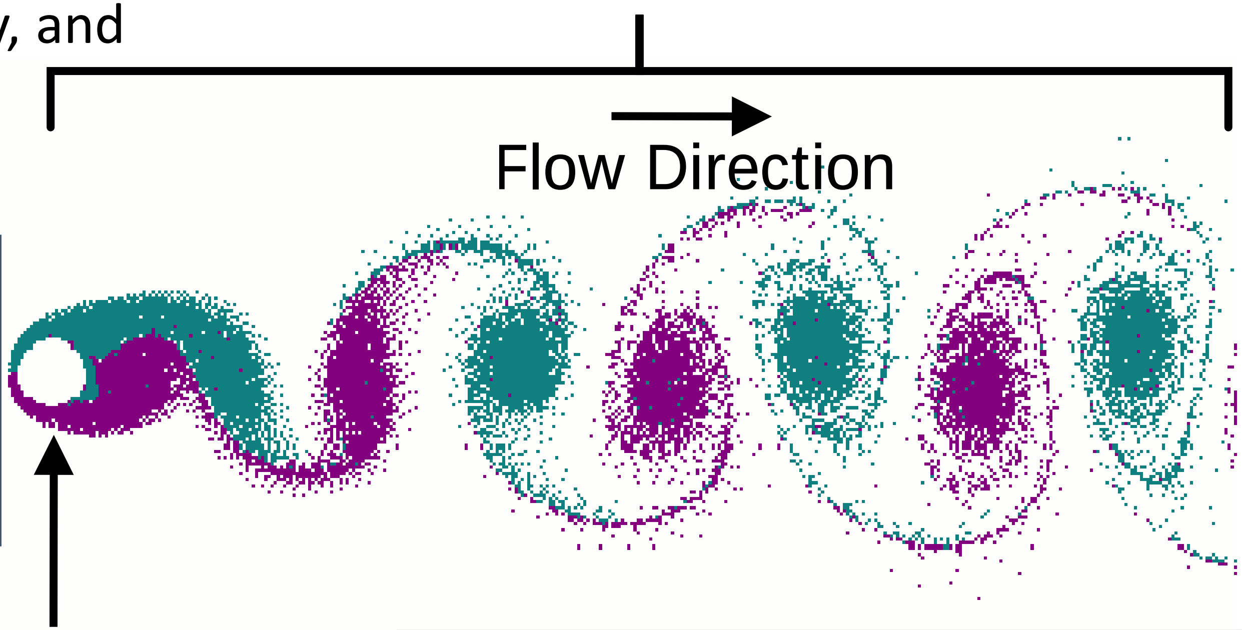


Vortex-Shedding and Strouhal Number

- Vortex-Shedding occurs at flow disturbances
- Vortices form as a result of the flow disturbance
- Thermowell or Tee = flow disturbance
- Strouhal number defines relationship between the vortex-shedding frequencies, system geometry, and fluid properties



(Images courtesy of S. Dequand, et al.)



Link to animation webpage:

http://disc.sci.gsfc.nasa.gov/oceancolor/additional/science-focus/ocean-color/vonKarman_vortices.shtml

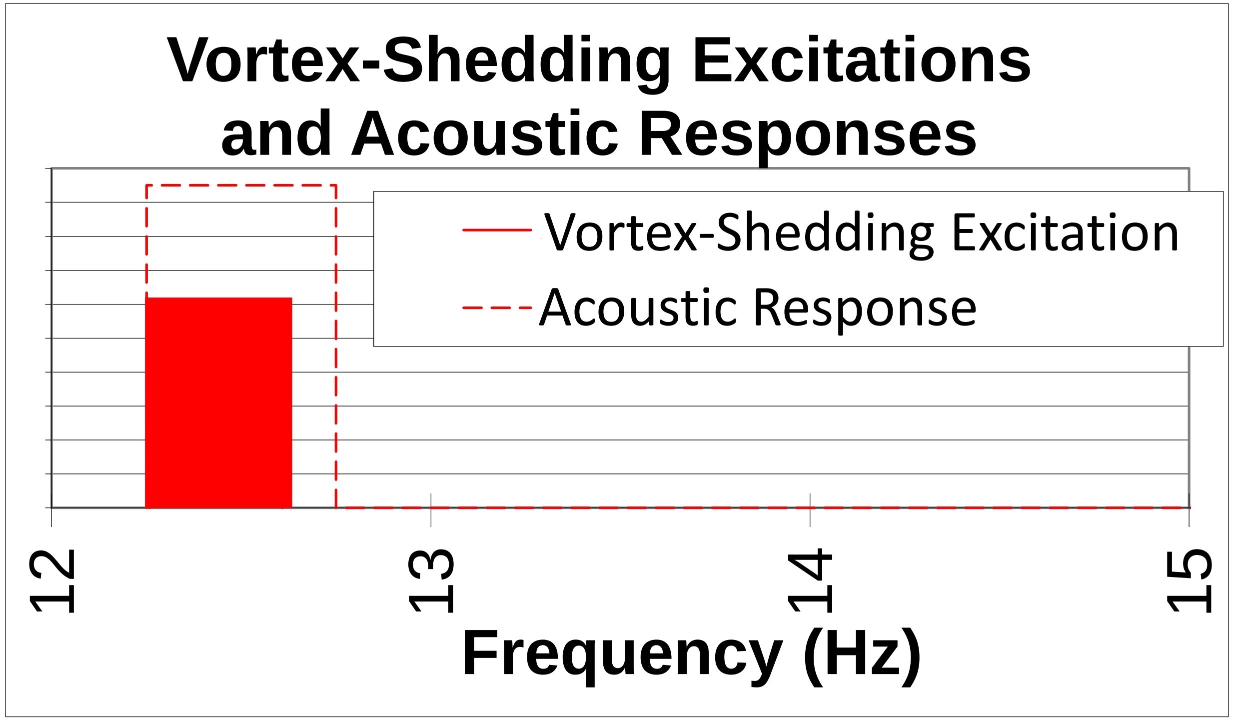
Vortex-Shedding Calculations Show Low Strouhal Number Needed for a Problem to Occur

- Strouhal number is a useful non-dimensional parameter that relates disturbance frequency to flow-speed, size of the flow disturbance, and geometric configuration.
- Vortex shedding frequency is dictated by the Strouhal number

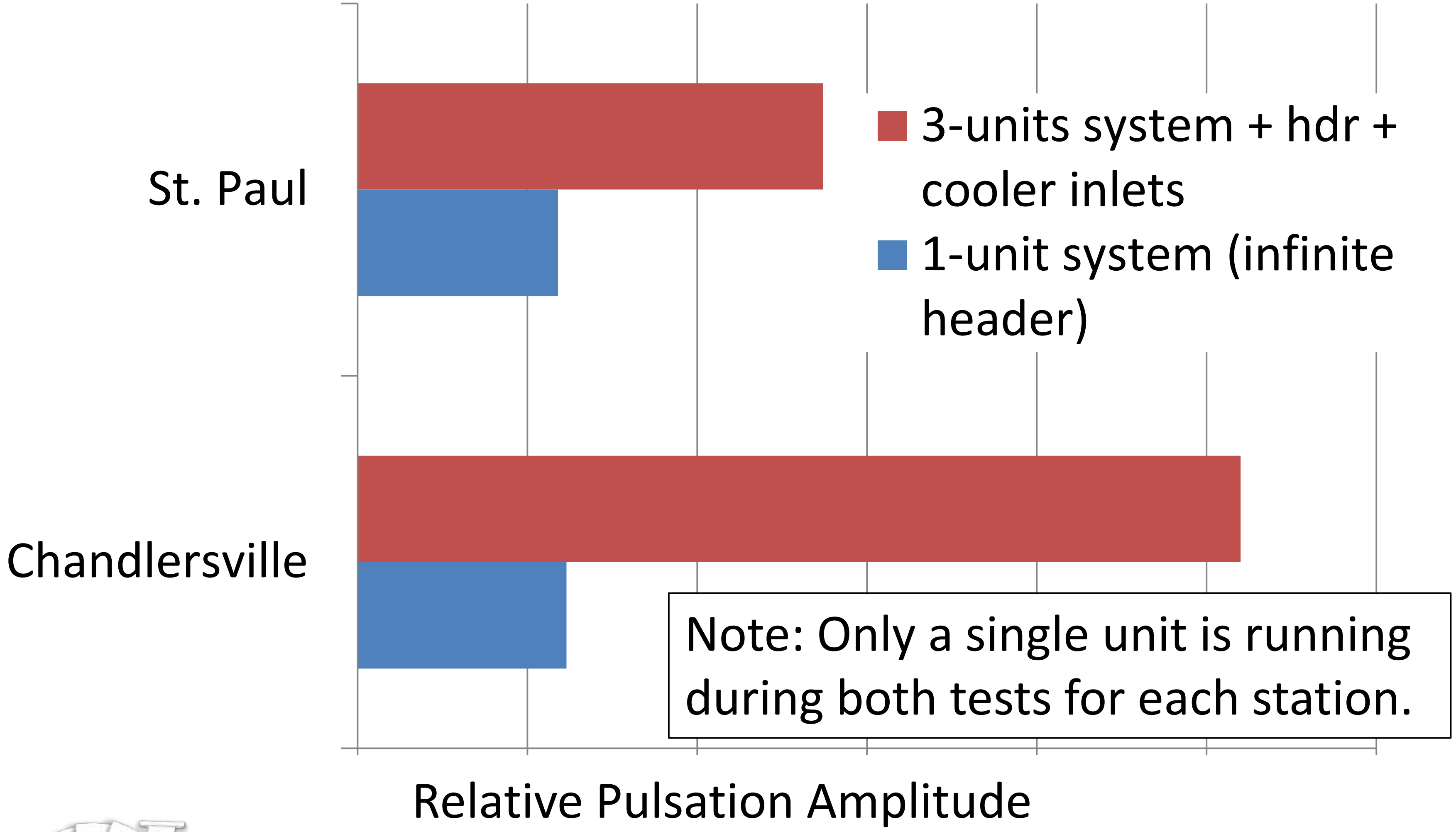
$$S_t = \frac{f_s d}{U}$$

f_s is the shedding frequency or frequency,
d is characteristic dimension of object generating disturbance (such as diameter of the branch piping in this case) and
U is flow speed (velocity)

- Strouhal number calibrated based on field data
- St = (12.5 Hz x 0.98 ft)/(47 ft/s) = 0.26



Modeling Indicates *System* Acoustic Response is Excited



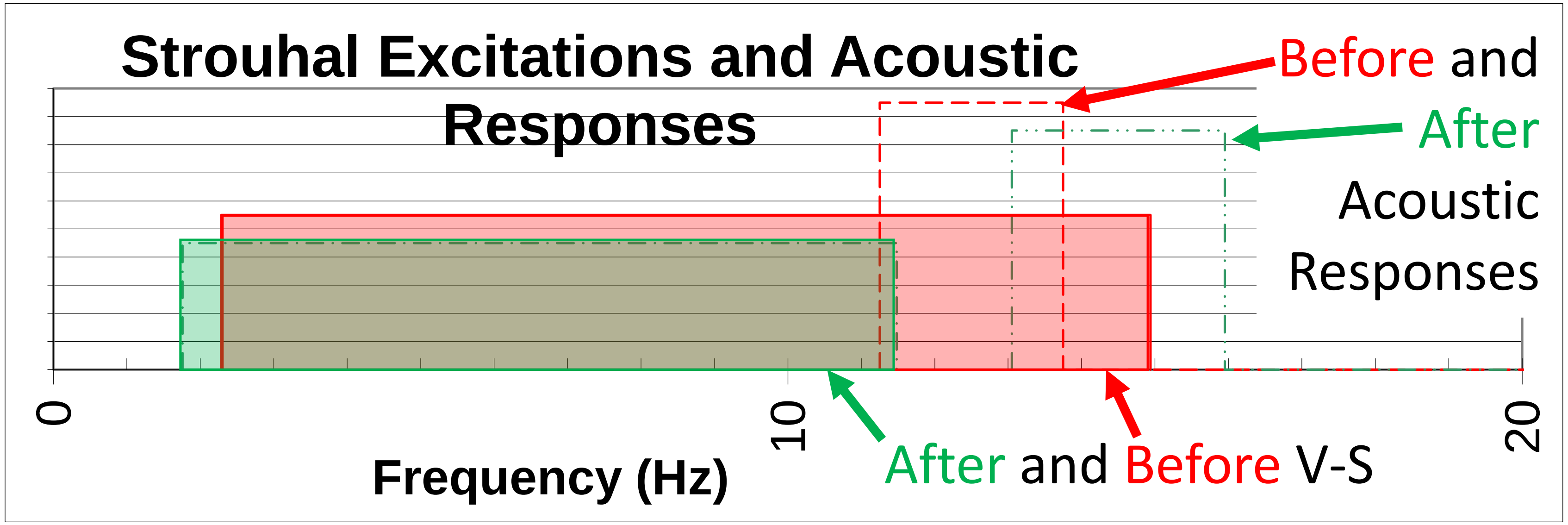
Note: Only a single unit is running during both tests for each station.

- Pulsation measured in recycle piping at field tap location (recycle valve closed)
- Pulsation in recycle piping for larger (3-units) system resulted in much higher amplitude than simplified (1-unit) system
- Conclusion: The acoustic response is a function of the entire piping system, not just a localized issue

Modeling Indicated Acoustic Shift and Lower Amplitudes with Piping Modification

- ~75% pulsation amplitude reductions predicted at peak pulsation amplitude locations when implementing tee diameter increase & reducer for the center unit only

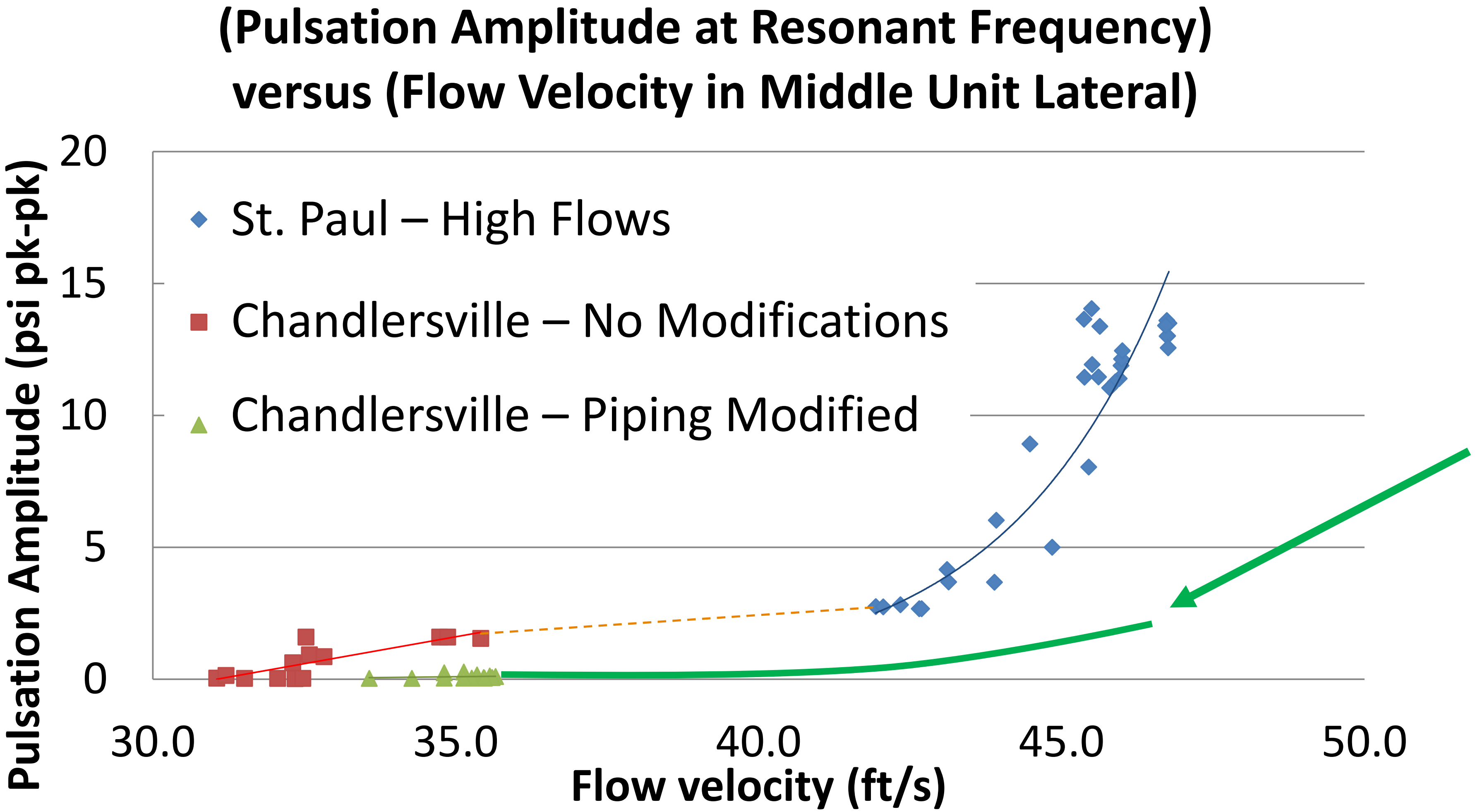
- No excitation predicted for center unit
  - Acoustic natural frequency shifts **up** due to piping modification
  - Vortex-Shedding (V-S) excitation frequency shifts **down** due to piping modification


Strouhal Excitations and Acoustic Responses

Conclusions: Vortex-Shedding Vibrations Summary

- Problem described – high vibrations and pulsations
- Flows not unusually high.
- ~12.5 Hz acoustic response + piping vibration **does** go away when the recycle valve is cracked
- ~12.5 Hz acoustic response + piping vibration does **not** track with compressor running speed
- ~12.5 Hz acoustic response + piping vibration **does** change as operating conditions change
- Entire system needed to be modeled to determine why the acoustic response was so dominant (significantly excited)
- Solution – alter the acoustics with the piping modification shown on the previous slide

Follow-up Field Testing: Pulsation Amplitudes Reduced After Piping Modification



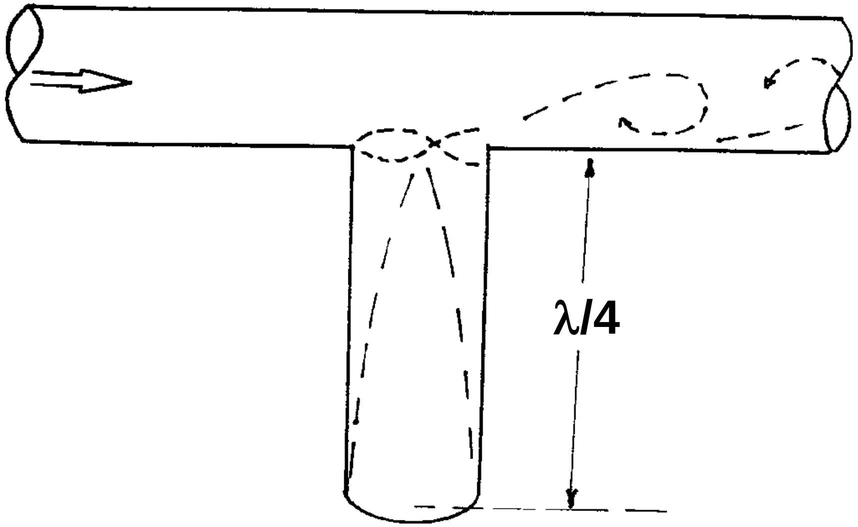
Follow-up data was not available for St. Paul, but it is estimated to be as depicted <u>or less</u>.

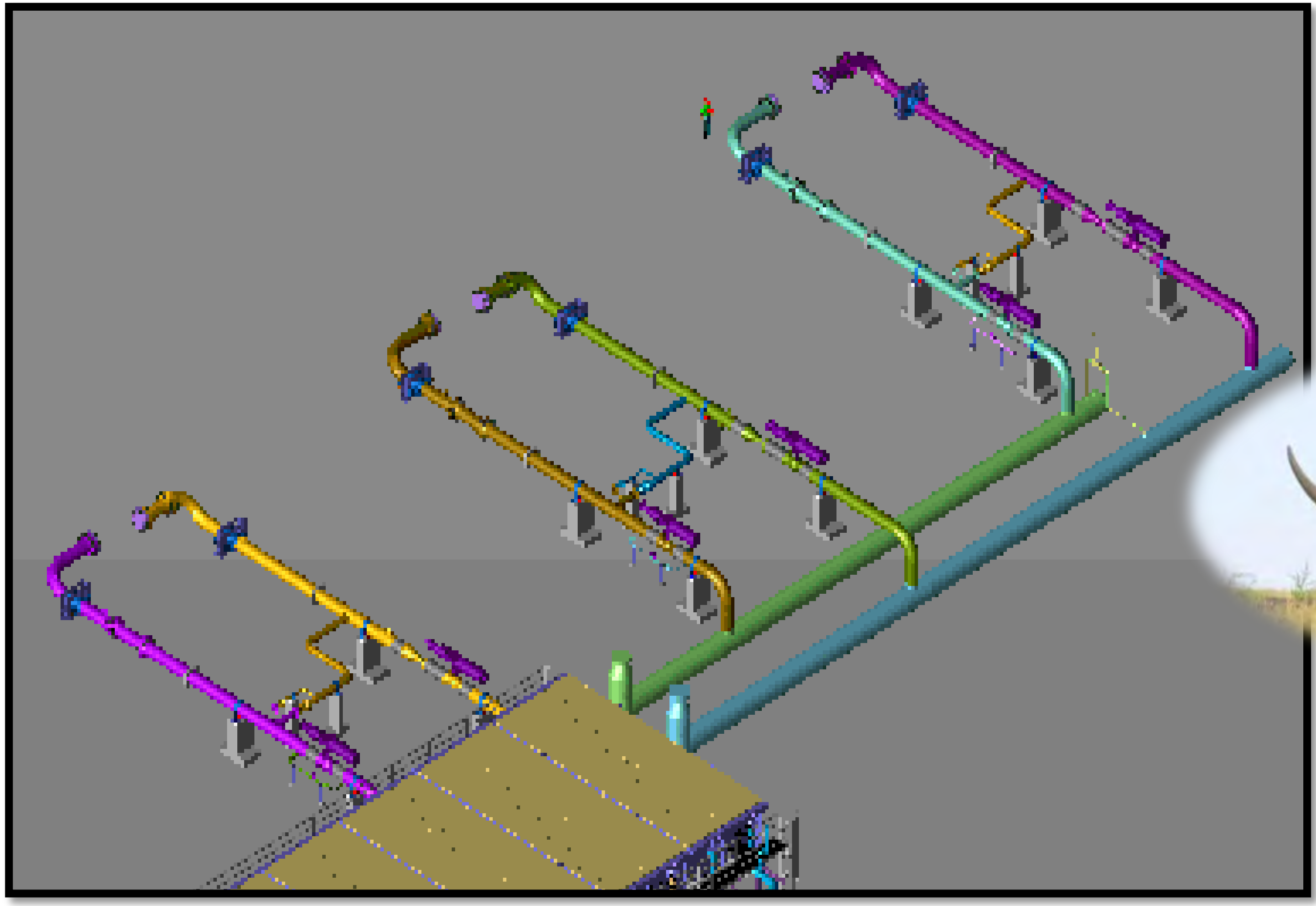
Tallgrass confirmed that they no longer have problems.

Lessons Learned: Piping Restraints & Acoustics

- Piping vibration is a function of both the excitation in the piping and how well the piping is physically restrained.
- If pulsation levels are low in amplitude, then effective mechanical restraint will often adequately control vibration.
- However, many non-recip piping systems are often restrained with more flexible “guide” type restraints that do not provide effective vibration control.
- New techniques are emerging in industry (by SwRI & others) to predict pulsation amplitudes (instead of old-school frequency avoidance methodologies). This can result in pulsation energy in the piping.
- Effective clamping must be considered as part of the design.
- Significant acoustic amplification can occur for parallel systems at lower Strouhal numbers – greater amplification than individual systems or localized responses (for additional details reference to similar phenomenons *Zaida, S. and Shine, S., 1999*)

Thank You. Questions?





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