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Vibration integrity management

New tools to avoid fatigue failure

Speaker

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Static Equipment and Structures, Wood

- 16 years' industry experience
- Field of expertise: vibration engineering

Agenda

1. Introduction
2. Conclusions from 2017 Presentation
3. Complementary approach to RBI (API 570)
4. Excitation mechanisms
5. How companies can asses vibration risks
6. Recommendations
7. Conclusion

Introduction

- Vibration-related fatigue failure on piping is a real threat to facilities
- Vibration should be included in integrity programs
- How can owners/operators be proactive to understand this risk?
- How can owners/operators take corrective action before the failure and loss of containment occurs?

Conclusions (from 2017)

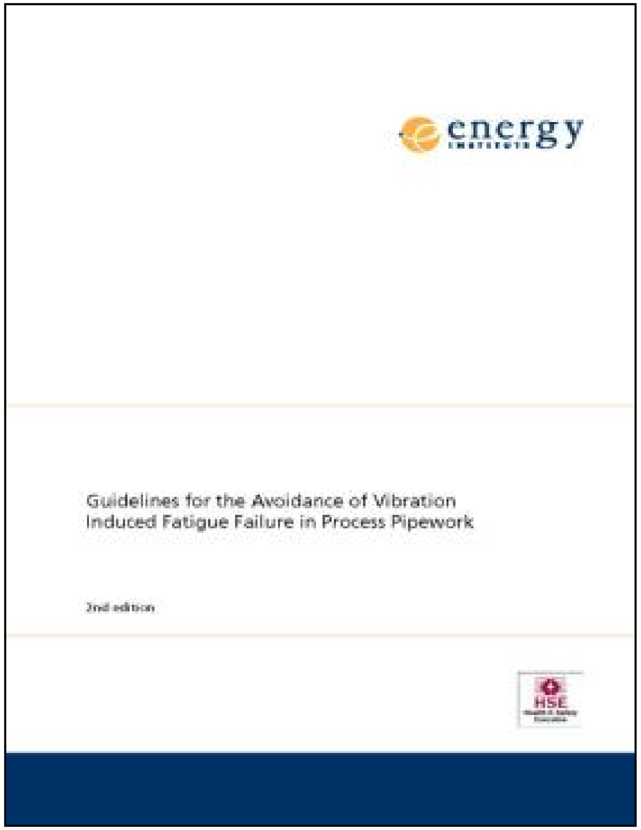
- Vibration is a **significant threat** to facility integrity
- Vibration is **not managed effectively** in most integrity programs
- **Tools and experience exist** to assist integrity professionals
- Vibration **screening is complementary** to integrity methods
- **Field vibration measurement is effective** alongside NDT

A successful integrity program includes vibration considerations

Avoid surprises!

Energy Institute

Guidelines for the **Avoidance of Vibration Induced Fatigue Failure** in Process Pipework
2nd Ed., 2008 (EI **AVIFF**)

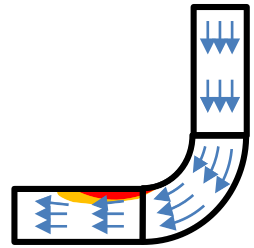


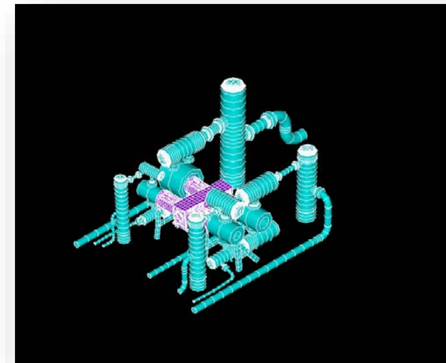
Complementary approach to API 570

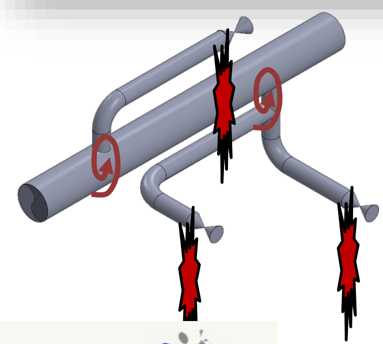
Piping mechanical integrity (per **API 570**)	Vibration assessment (per **EI guidelines**)
What's in scope?	
Consequence and criticality assessment determines priority lines to focus on (safety and production critical)	Typically includes a mainline assessment (primary process piping) and rotating equipment
What could go wrong?	
Markup PFDs / P&IDs (circuitization) Identify likely damage mechanisms	Small-bore connections, reciprocating equipment, turbulence, flare lines, valves, resonance
How bad is it?	
Assess process and materials to determine corrosion and environmental cracking threats	Assess vibration mechanisms using appropriate screening tools
How can we manage it?	
• Develop inspection test plans (ITPs) • Process/materials recommendations • Establish integrity operating windows (IOWs)	Inspection locations included in ITP • Engineered solutions (clamps, braces, etc) • IOWs (flow limits, equipment speed range) • Manage anomalies until close-out

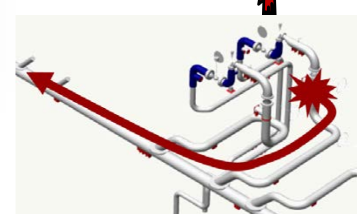
Excitation mechanisms from EI AVIFF

- Flow-induced turbulence
- Mechanical excitation and pulsation
- Pulsation: rotating stall
- Pulsation: flow-induced excitation
- High-frequency acoustic excitation
- Surge: momentum changes due to valve operation
- Cavitation and flashing



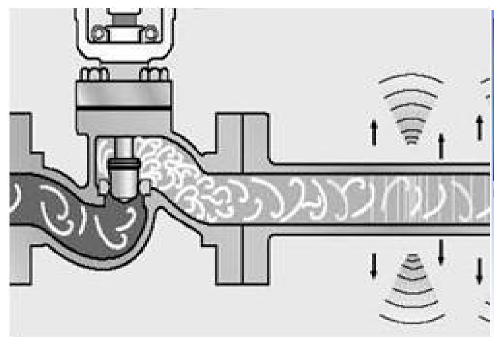


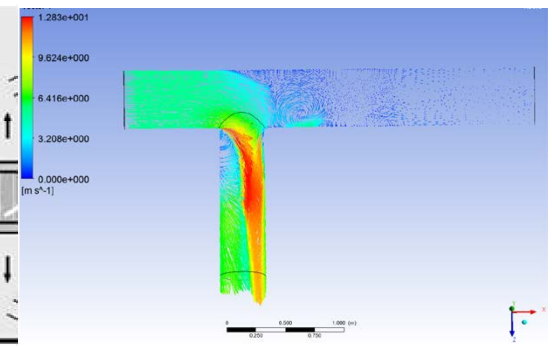




Flow-induced turbulence (FIT)

- Dominant source for FIV turbulence is generated at flow discontinuities in the system, such as:
  - Process equipment
  - Partially closed valves
  - Short radius or mitred bends
  - Tees and reducers

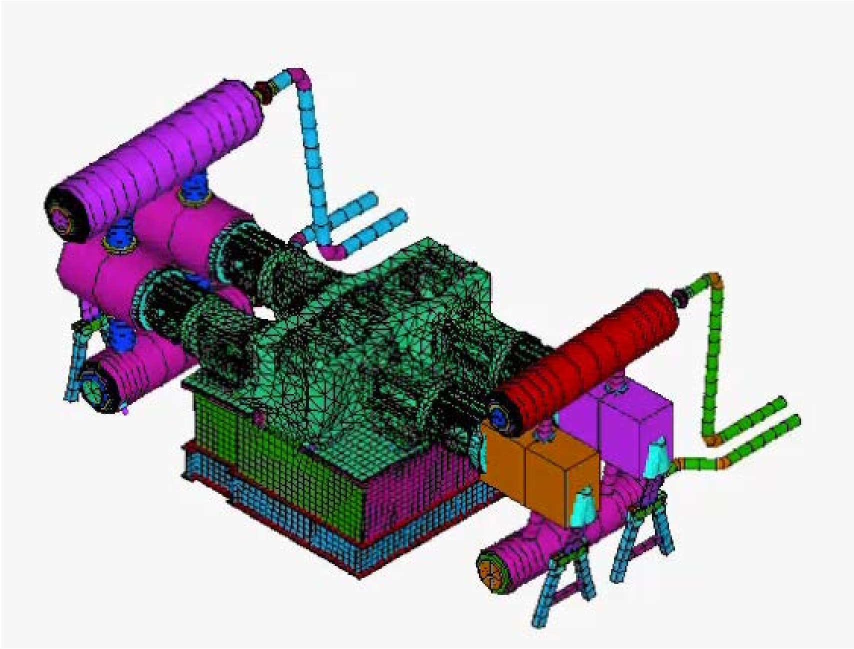




- Turbulence is generated in fluid flowing in piping, leading to vibration with frequency ranges up to 200 Hz

Mechanical excitation and pulsation

- Reciprocating and positive displacement machines
- Energy at orders of operating speed
- Mechanical excitation close to compressors
- Uncontrolled pulsations travel upstream and downstream, impact piping

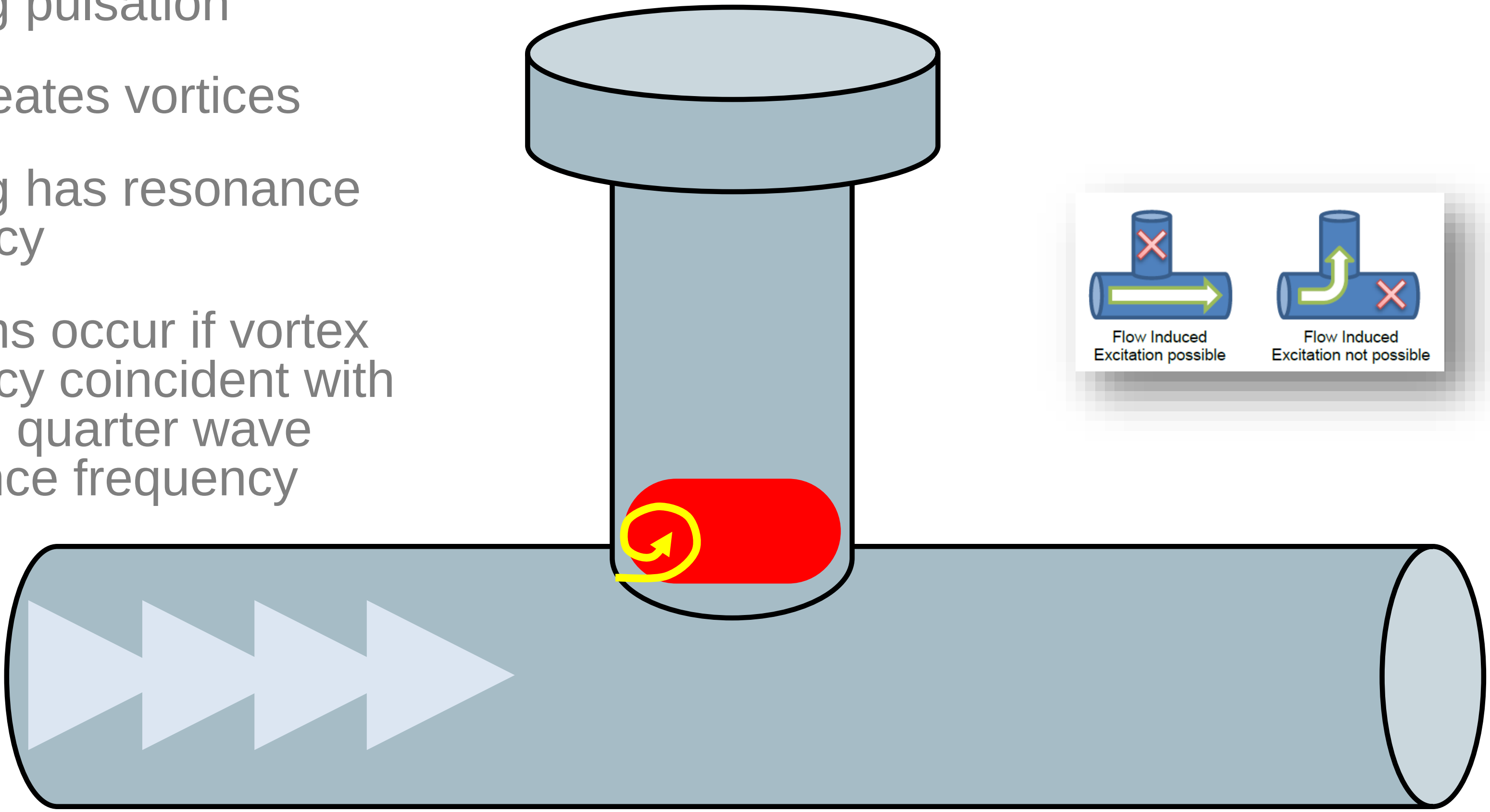


Pulsation: rotating stall

Creates sub-synchronous pulsations

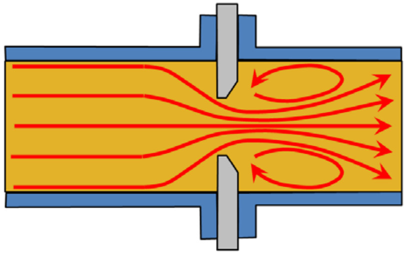
Pulsation: flow-induced excitation

- Deadleg pulsation
- Flow creates vortices
- Deadleg has resonance frequency
- Problems occur if vortex frequency coincident with deadleg quarter wave resonance frequency

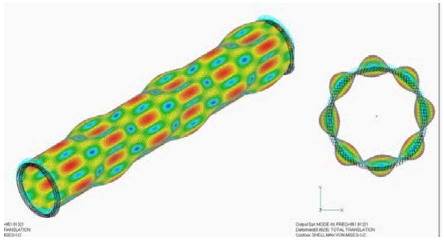


High-frequency acoustic excitation (AIV)

- High levels of acoustic energy can be generated in high-capacity gas-pressure-reducing systems such as:
  - Pressure relief
  - Blow down
  - Flow or pressure control



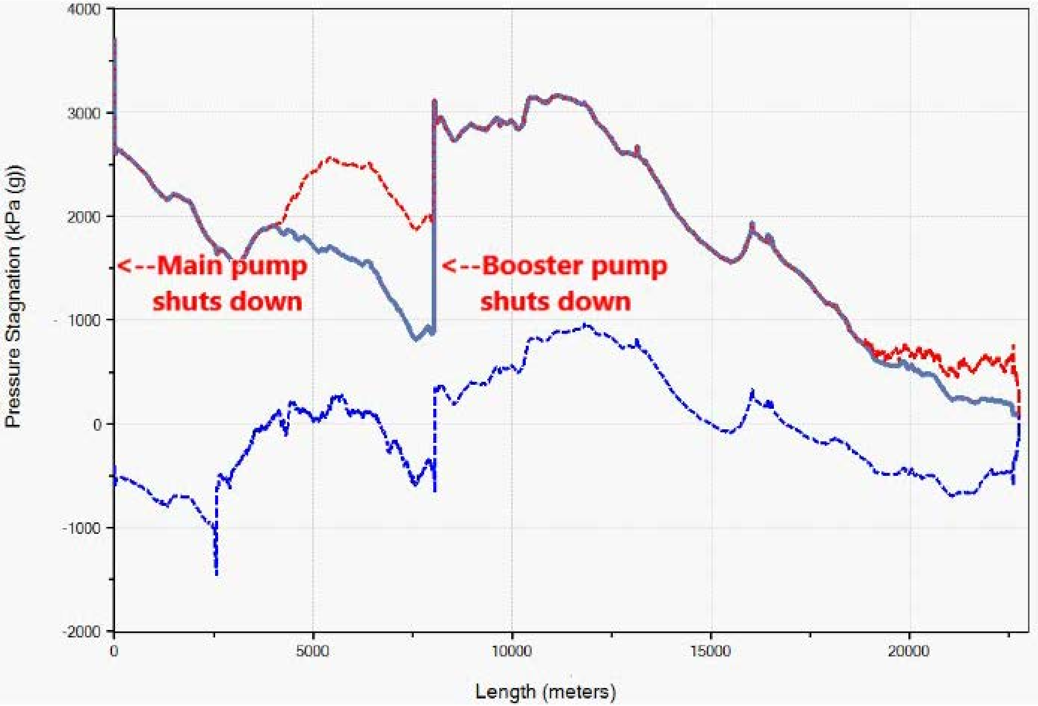
- High levels of acoustic energy can **result in severe piping vibration**, leading to piping component fatigue failure in as little as a few hours
  - Typical frequency range: 300 Hz to 4000 Hz



High-frequency acoustic excitation (AIV)

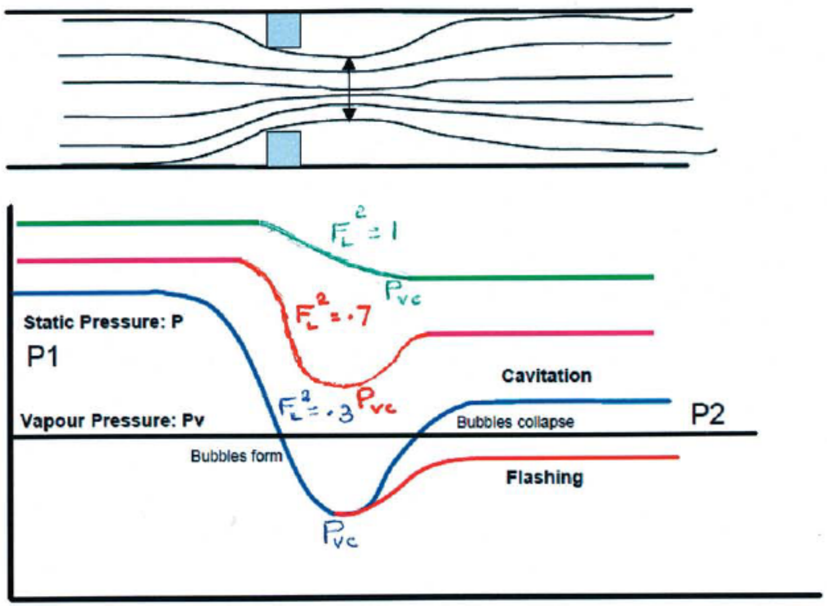
Surge: momentum changes due to valve operation

- Localized changes in the fluid velocity
  - Valve closing
  - Pump start and stop
- Pressure peaks traveling through the pipe
  - Excitation of localized pipe resonance
  - Trip relief valve



Cavitation and flashing

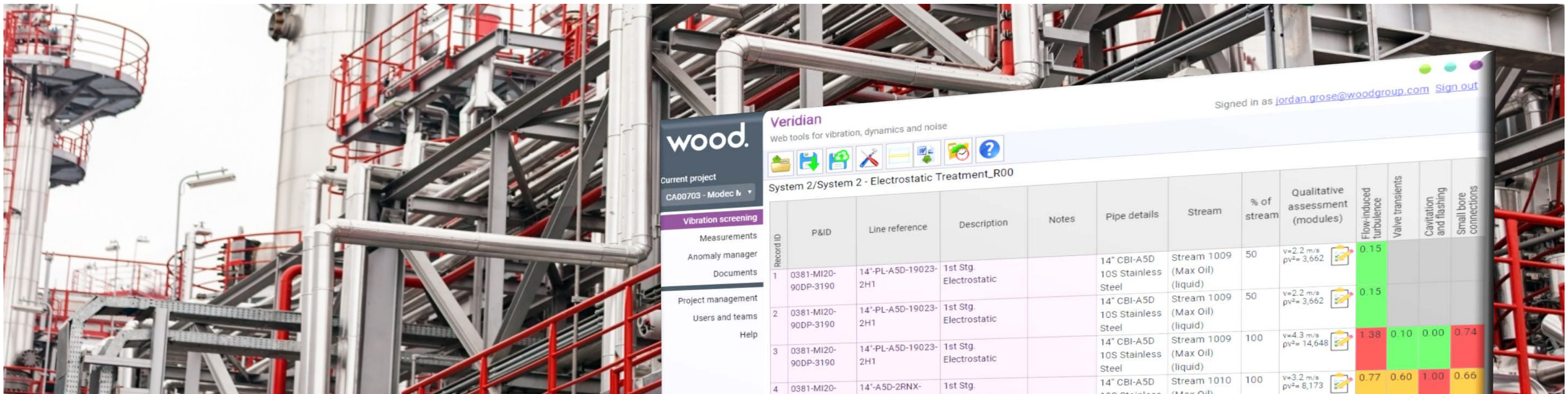
- When local pressure in liquid goes below vapor pressure
- Occurs near pressure-reducing areas like pump inlets, valves, orifice plates
- Cavitation is when the bubbles quickly collapse
- Flashing is when the bubbles remain in the liquid

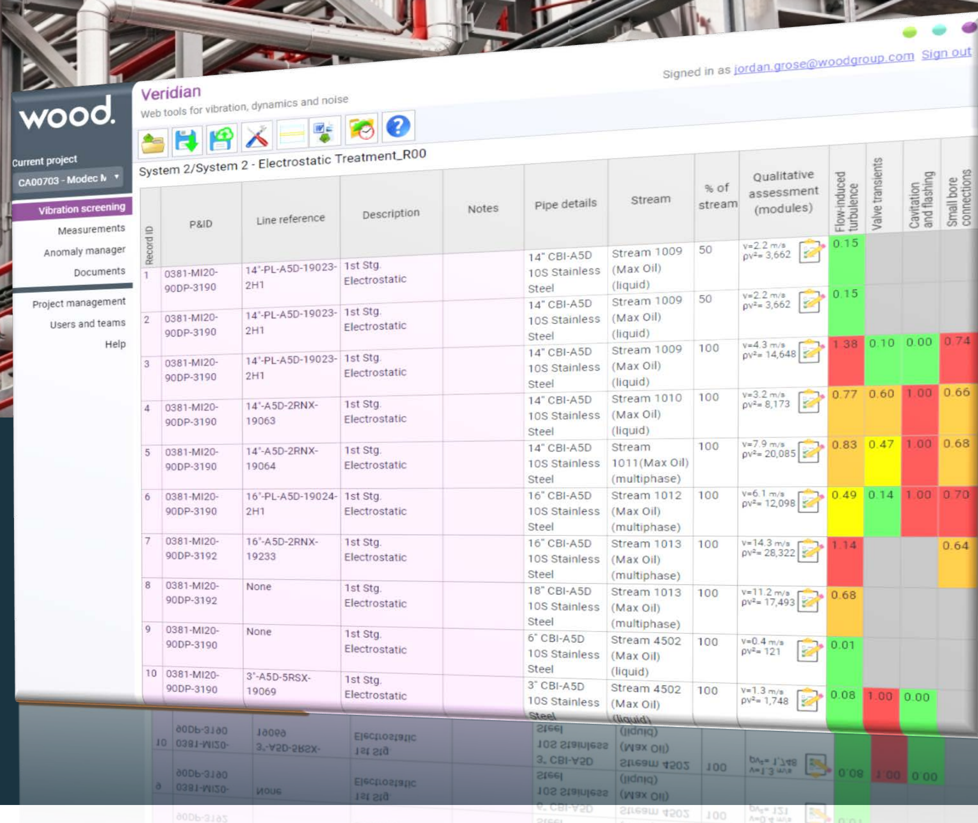


How you do know when to be worried?

Know where to focus your efforts

Vibration screening tool Veridian





Free, web-based application that applies the EI standard to proactively identify piping vibration integrity threats

Vibration screening approach

Design stage

Operational plant

Piping information

Vibration screening

Process information

Identify hotspots

Target actions

Enter piping information

Design stage

Operational plant

Piping information

Vibration screening

Process information

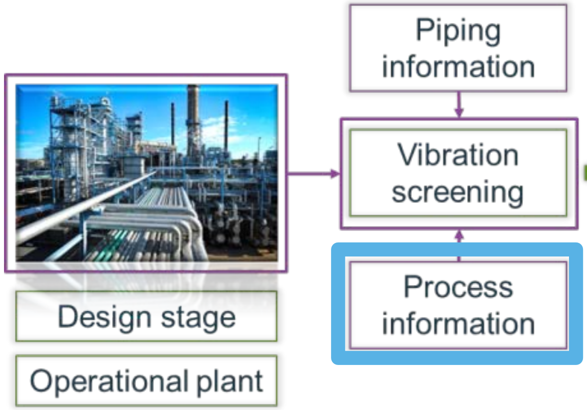
Identify hotspots

Target actions

Piping details - Upstream of E401

Select below	Spec.	Nominal bore	Schedule	Outside diameter [mm]	Wall thickness [mm]	Liner thickness [mm]	Material	Pipe Pressure Rating [bara]
14" STD Carbon Steel		14"	STD	355.6	9.525		Carbon Steel	
8" 120 Carbon Steel		8"	120	219.075	18.263		Carbon Steel	
4" 120 Carbon Steel		4"	120	114.3	11.125		Carbon Steel	
6" STD Carbon Steel		6"	STD	168.275	7.112		Carbon Steel	
20" STD Carbon Steel		20"	STD	508	9.525		Carbon Steel	
12" STD Carbon Steel		12"	STD	323.85	9.525		Carbon Steel	
10" STD Carbon Steel		10"	STD	273.05	9.271		Carbon Steel	

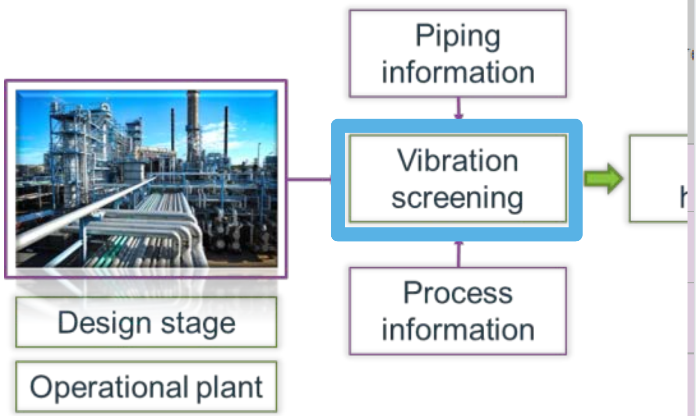
Enter stream information



Stream details - Upstream of E401

Select below	Description	Phase	Mass flow rate [kg/h]	Temperatu [°C]	Density [kg/m³]	Static pressure [Bara]	Dynamic viscosity [Pa.s]	Speed of sound [m/s]	Gamma (c_p/c_v) [#]	Molecular weight [g/mol]
Select Stream 4(gas)	Stream 4	gas	59358	141.9	18	26	.00002	425.79840	1.22	23.22
Select Stream 5(gas)	Stream 5	gas	59358	30	26	24.5	.00001	375.64219	1.3	23.22
Select Stream 6(gas)	Stream 6	gas	53482	30	23	24.5	.00001	394.05474	1.34	21.75
Select Stream 7(gas)	Stream 7	gas	53482	136.7	62	88	.00002	456.4	1.33	21.75
Select Recycle low pressure(gas)	Recycle low pressure	gas	53482	141.9	18	26	.00002	425.79840	1.22	23.22
Select Relief high pressure(gas)	Relief high pressure	gas	53482	136.7	62	88	.00002	456.4	1.33	21.75
Select Relief low pressure(gas)	Relief low pressure	gas	53482	88	4	1	.00001	428.4	1.33	21.75
Select Stream 1 (original)(multiphase)	Stream 1 (original)	multiphase	461764	50	930	6.5	0	310.80779	1.01	28.09
Select Stream 2 (original)(gas)	Stream 2 (original)	gas	27180	50	5	6.5	.00001	389.22911	1.24	21.99
Select Stream 3 (original)(liquid)	Stream 3 (original)	liquid	303180	50	930	6.5	.3935	275.28103	1.08	38.29

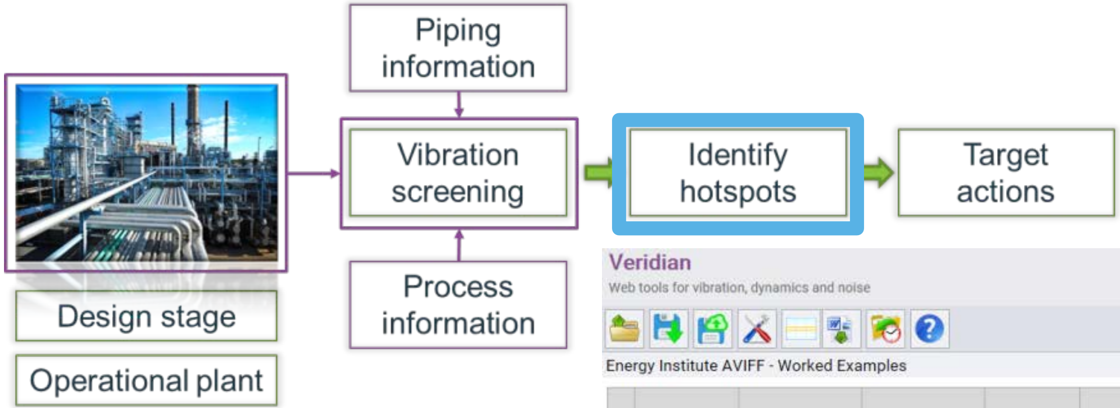
Qualitative screening



Modules / Qualitative Assessment

(FIT) Flow-induced turbulence (EI AVIFF Guidelines T2.2)	(fit)
Is the maximum value of kinetic energy (ρv²) of the process fluid above 5000 kg/m s²?	Yes
Mechanical Excitation (EI AVIFF Guidelines T2.3)	(mex)
Is there any rotating or reciprocating machinery?	No
Pulsation from reciprocating items (EI AVIFF Guidelines T2.4)	(rec)
Are there any positive displacement pumps or compressors?	No
Pulsation from rotating stall (EI AVIFF Guidelines T2.5)	(rst)
Are there any centrifugal compressors which have the potential to operate under rotating stall conditions?	No
Pulsation from corrugated pipes (EI Subsea AVIFF Guidelines E4.3)	(cor)
Does the system contain any rough bore flexibles?	No
(AIV) High frequency acoustic excitation (EI AVIFF Guidelines T2.7)	(aiv)
Is choked flow possible, or are sonic flow velocities likely to be encountered? **only applies to pressure reducing systems, not the main line**	No
Valve transients (EI AVIFF Guidelines T2.8)	(tra)
Are there any fast acting opening or closing valves?	No
Thermowells (ASME PTC 19.3 TW - 2016)	(thw)
Are there any intrusive elements in the process stream?	No
(SBC) Small bore connections (EI AVIFF Guidelines)	(sbc)
Are any of the main line LOF's ≥ 0.3?	No

Qualitative screening



Veridian

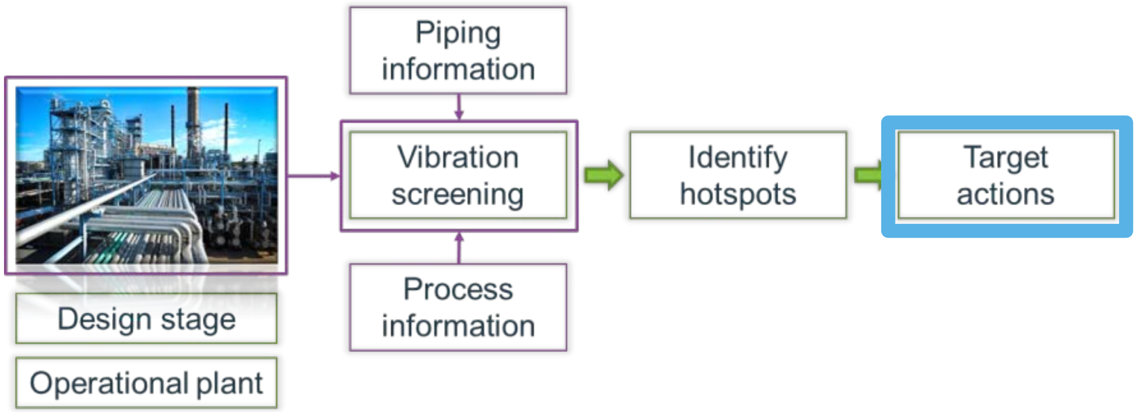
Web tools for vibration, dynamics and noise

Signed in as internal.demo Sign out

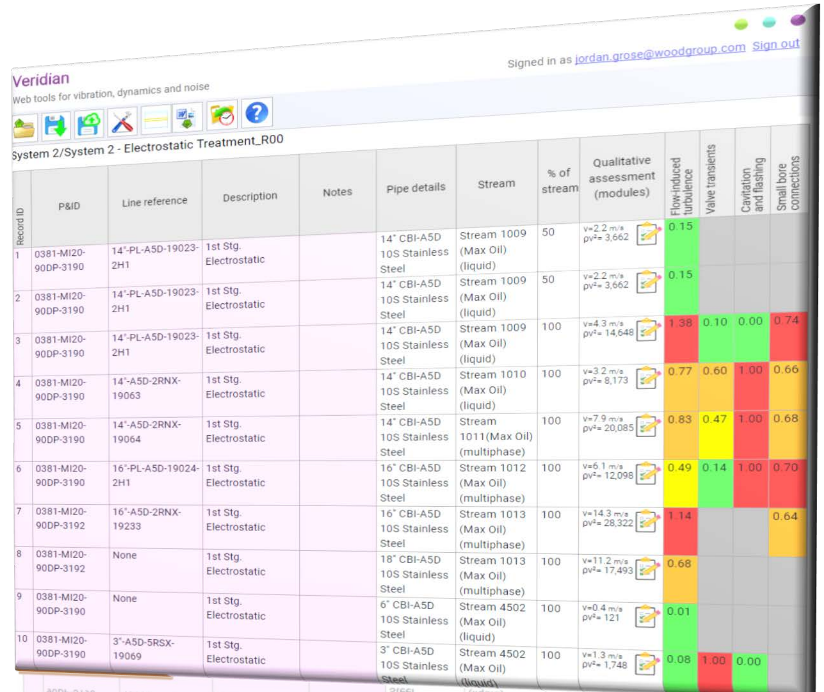
Energy Institute AVIFF - Worked Examples

Record ID	P&ID	Line reference	Description	Notes	Pipe details	Stream	% of stream	Qualitative assessment (modules)	Flow-induced turbulence	Mechanical excitation	Pulsation Recip/PD	Pulsation from rotating stall	Pulsation from deadlegs	Pulsation from corrugations	Slugging flow	High frequency acoustic excitation	Valve transients	Cavitation and flashing	Thermowells	Small bore connections
1	Figure D-1	Stream 4	Upstream of E401		14" STD Carbon Steel	Stream 4 (gas)	100	v=10.3 m/s ρv²= 1,909	0.01				0.00							
2	Figure D-1	Stream 5	Downstream of E401, upstream of		14" STD Carbon Steel	Stream 5 (gas)	100	v=7.1 m/s ρv²= 1,321	0.01				0.00							
3	Figure D-1	Stream 6	Downstream of V402, upstream of		14" STD Carbon Steel	Stream 6 (gas)	100	v=7.3 m/s ρv²= 1,213	0.01	0.40			0.00						0.29	
4	Figure D-1	Stream 7	Downstream of K402		8" 120 Carbon Steel	Stream 7 (gas)	100	v=9.2 m/s ρv²= 5,197	0.02	0.40			1.00							0.66
5	Figure D-1	Recycle line (compressor	From downstream of K402 back to		8" 120 Carbon Steel	Stream 7 (gas)	100	v=9.2 m/s ρv²= 5,197	0.02	0.40			0.00			0.29				
6	Figure D-1	Recycle line (compressor	From upstream of recycle valve to		6" STD Carbon Steel	Recycle low pressure(gas)	100	v=44.3 m/s ρv²= 35,294	0.28				0.00			0.29				
7	Figure D-1	Relief line (upstream of PSV)	Downstream of K402 to upstream		4" 120 Carbon Steel	Relief high pressure(gas)	100	v=36.0 m/s ρv²= 80,379	0.34	0.40			0.29				3.77			
8	Figure D-1	Relief line (downstream of	Downstream of PSV to flare		6" STD Carbon Steel	Relief low pressure(gas)	100	v=199 m/s ρv²= 1.59e5	0.88				1.00			1.48	1.77			
9	Figure D-3	Stream 1	From production		20" STD	Stream 1	100	v=9.3 m/s	0.26											

Target actions



Target actions



Record ID	P&ID	Line reference	Description	Notes	Pipe details	Stream	% of stream	Qualitative assessment (modules)	Flow-induced turbulence	Valve transients	Cavitation and flashing	Small bore connections
1	0381-MI20-90DP-3190	14"-PL-A5D-19023-2H1	1st Stg. Electrostatic		14" CBI-A5D 10S Stainless Steel	Stream 1009 (Max Oil) (liquid)	50	v=2.2 m/s ρv²= 3,662	0.15			
2	0381-MI20-90DP-3190	14"-PL-A5D-19023-2H1	1st Stg. Electrostatic		14" CBI-A5D 10S Stainless Steel	Stream 1009 (Max Oil) (liquid)	50	v=2.2 m/s ρv²= 3,662	0.15			
3	0381-MI20-90DP-3190	14"-PL-A5D-19023-2H1	1st Stg. Electrostatic		14" CBI-A5D 10S Stainless Steel	Stream 1009 (Max Oil) (liquid)	100	v=4.3 m/s ρv²= 14,648	1.38	0.10	0.00	0.74
4	0381-MI20-90DP-3190	14"-A5D-2RNX-19063	1st Stg. Electrostatic		14" CBI-A5D 10S Stainless Steel	Stream 1010 (Max Oil) (liquid)	100	v=3.2 m/s ρv²= 8,173	0.77	0.60	1.00	0.66
5	0381-MI20-90DP-3190	14"-A5D-2RNX-19064	1st Stg. Electrostatic		14" CBI-A5D 10S Stainless Steel	Stream 1011(Max Oil) (multiphase)	100	v=7.9 m/s ρv²= 20,085	0.83	0.47	1.00	0.68
6	0381-MI20-90DP-3190	16"-PL-A5D-19024-2H1	1st Stg. Electrostatic		16" CBI-A5D 10S Stainless Steel	Stream 1012 (Max Oil) (multiphase)	100	v=6.1 m/s ρv²= 12,098	0.49	0.14	1.00	0.70
7	0381-MI20-90DP-3192	16"-A5D-2RNX-19233	1st Stg. Electrostatic		16" CBI-A5D 10S Stainless Steel	Stream 1013 (Max Oil) (multiphase)	100	v=14.3 m/s ρv²= 28,322	1.14			0.64
8	0381-MI20-90DP-3192	None	1st Stg. Electrostatic		18" CBI-A5D 10S Stainless Steel	Stream 1013 (Max Oil) (multiphase)	100	v=11.2 m/s ρv²= 17,493	0.68			
9	0381-MI20-90DP-3190	None	1st Stg. Electrostatic		6" CBI-A5D 10S Stainless Steel	Stream 4502 (Max Oil) (liquid)	100	v=0.4 m/s ρv²= 121	0.01			
10	0381-MI20-90DP-3190	3"-A5D-5RSX-19069	1st Stg. Electrostatic		3" CBI-A5D 10S Stainless Steel	Stream 4502 (Max Oil) (liquid)	100	v=1.3 m/s ρv²= 1,748	0.08	1.00	0.00	

When to perform a screening and why?

- New facility
  - FEED
  - Detailed design
  - Results in a better designed system
- Existing facility
  - If vibration risk is unknown
  - When facility requirements change (during management of change)
  - Increased throughput
  - When designing the upgrade of a facility
  - Enables owners to know where to focus their effort

Vibration screening (VS) can fill the gap

Case study

- Work scope: two assessments
  1. FIV on all main-line, hydrocarbon process pipework
  2. AIV on flare system pipework
- Three different facility design cases (including 100% and 120% design)
- All main-line pipework assessed for:
  - Flow-induced turbulence
  - Flow-induced pulsation/vibration (FIV)
  - Mechanical
  - Machinery-generated pulsation (reciprocating compressors)
  - Fast acting valves – eg, flashing, cavitation

FIV results and recommendations

66 required actions identified

- 2 **critical priority** actions – require immediate attention
- 6 **high priority** actions – closeout target date <3 month
- 58 **medium priority** action – closeout target date <6 month
- (+ 61 **low priority** actions – closeout target date <12 month)

Specific actions required:

- 13 anti-vibration brace drawings for fabrication, installation and subsequent operator check measurements
- 11 engineering actions
- 6 engineering actions followed by subsequent operator check measurements
- 18 check measurements
- 18 locations recommended for detailed vibration measurement survey under representative flow conditions

AIV results and recommendations

Identified 65 risk areas on flare piping and common 42” header; welded tee, side branch and pipe support connections

- 10 sliding shoe pipe supports on 42” header cleared, based on detailed FEA modeling
- 11 connections require visual inspection to confirm appropriate bracing has been installed
- 5 require valve diffuser performance – if better than assumed then can be removed from list
- 6 weldolets require bolted or welded 2–plane braces installed
- 3 fabricated tees with repads on 12” local header to be extended to full encirclement wraps
- 15 sliding shoe pipe supports on 42” header to be extended to full encirclement wraps
- 15 other tee connections with repads on 42” header to be extended to full encirclement wraps

Conclusion

- **Vibration** is a real threat that **should be included in an effective integrity program**
- Tools enable asset owners to **ensure current standards (EI) are applied**
- **Vibration screening tools** are available that implement the current standards (EI) to **quickly identify where attention is needed**
- **Required data is most likely already compiled** for your existing RBI program
- **Vibration can be managed proactively,** and this **allows owners to prevent costly fatigue failures**

Thank you

Michael Cyca

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Vibration dynamics and noise
Wood

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