Assessment and Resolution of Piping Vibration

INSPECTION & MECHANICAL INTEGRITY SUMMIT

Inspection, Mechanical Engineering, Corrosion & Materials

API

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BIO SLIDE

Author

- George Antaki, P.E.
- Chief Nuclear Engineer, Mechanical Division, Becht
- 47 years in pressure equipment and piping/pipelines
- Field of Expertise: Engineering, FFS, process and power plants tanks, vessels, and piping/pipelines.
- ASME B31 Mechanical Design Committee past-chair current member, ASME III Working Group Piping chairman, ASME O&M Piping Vibration subgroup, author of three textbooks on pressure equipment and piping-pipelines.

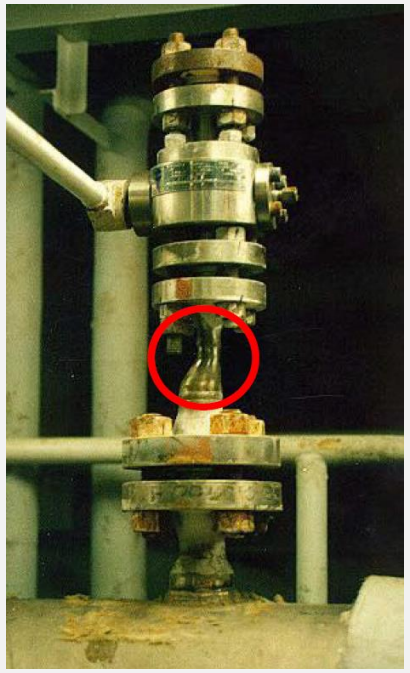
Substitute Presenter

- Charles Becht V, P.E.
- President, Becht
- 17 years in pressure equipment and piping
- Field of Expertise: Engineering, Advanced Analysis (CFD/FEA), FFS, process equipment (tanks, vessels, piping)

Challenges of Piping Vibration

The challenges of piping vibration

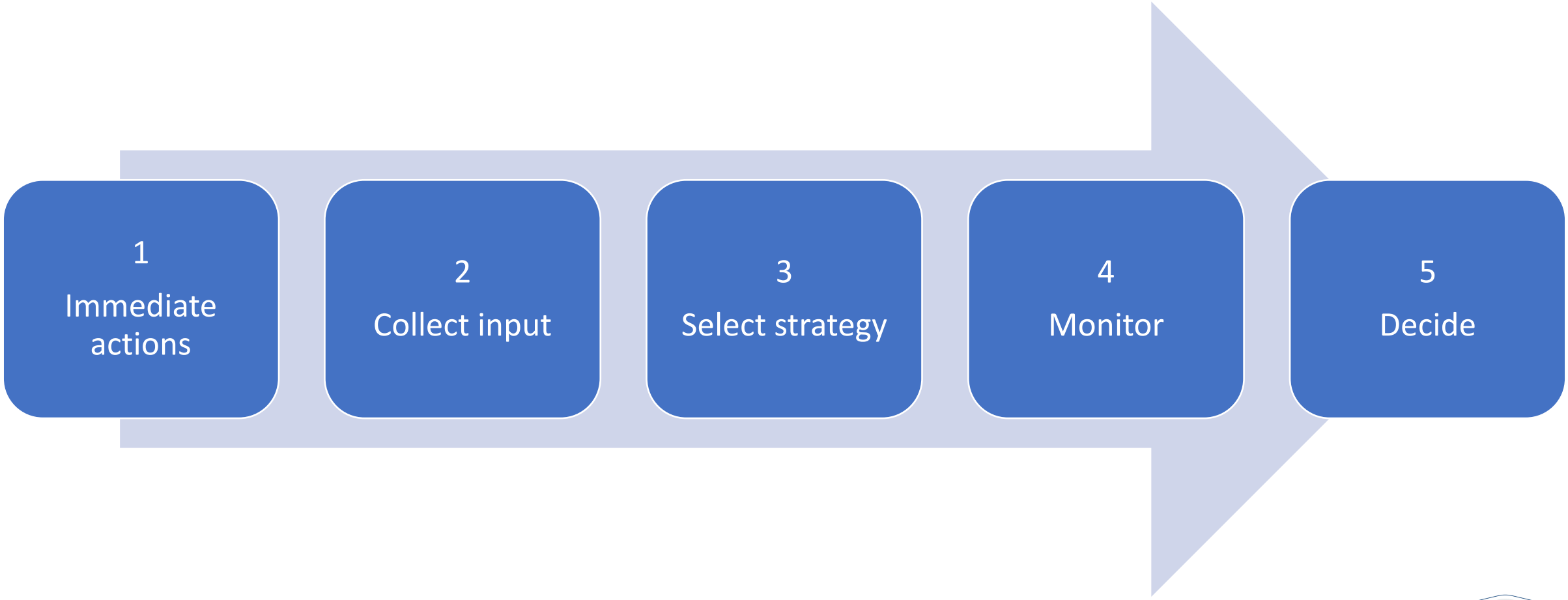
1. Can cause damage, leaks, ruptures.
   - Motivation for EI guidelines: 20% of hydrocarbon releases in the North Sea were due to vibration as well as 10-15% of land-based pipework failures in Western Europe.
2. Can cause malfunction of in-line active components.
   - Valve actuators, instruments, etc.
3. Vibration: The only load often ignored in piping system design.
   - Except gas compressor stations by API standards.
4. Not as mature as vibration diagnostic for rotating equipment.
5. Appears sometimes unexpectedly, after years of operation.
6. Lack of protocol for assessment and resolution.
   - Except gas compressor stations by API standards



References

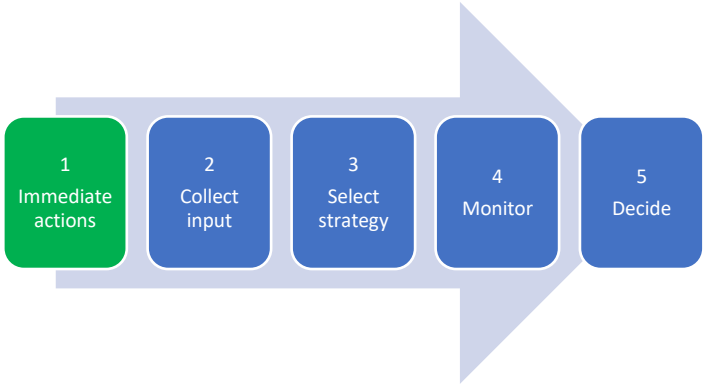
API 617 Standard, Axial and Centrifugal Compressors and Expander-Compressors.
API 618 Standard, Reciprocating Compressors for Petroleum, Chemical, and Gas Industry Services.
API RP-688 Recommended Practice, Pulsation and Vibration Control in Positive Machinery Systems for Petroleum, Petrochemical, and Natural Gas Industry Services.
API 579-1/ASME FFS-1 Fitness-for-Service, Draft Part 15 Piping Vibration (assessment of severity of measured vibration).
Gas Machinery Research Council, Pipeline Research Council International, and Southwest Research Institute (**GMRC, PRCI, SwRI**), Design Guideline for Small Diameter Branch Connections.
"Guidelines for the Avoidance of Vibration Induced Fatigue Failure in Process Pipework" by the **Energy Institute of the UK** Health & Safety Executive.
ASME "Operation and Maintenance of Nuclear Power Plants", Part 3, Vibration Testing of Piping Systems.

5-Step Approach



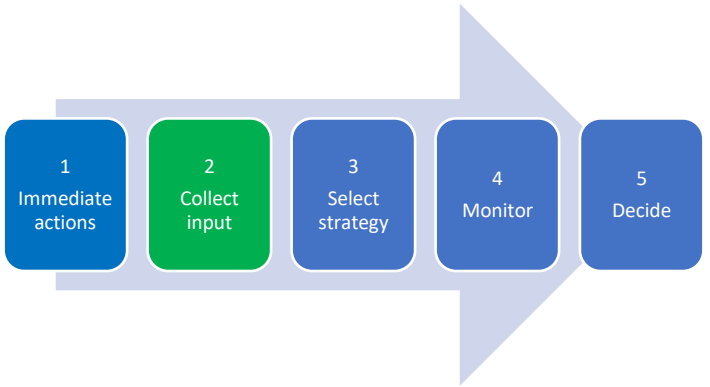
Step-1 Immediate Actions

Record the vibration (video)
Reduce flow rate, if required (severe movement or pressure pulsations)
Walkdown the system for support-restraint damage (record damage)



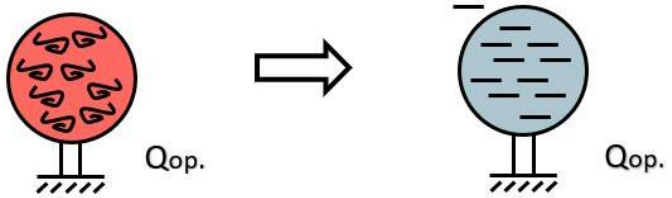
Step-2 Collect Input

1. System PQT during vibration.
2. P&ID highlighted flow path.
3. Isos highlighted flow path.
4. Hydraulic sizing – system.
5. Hydr. sizing – components.
6. Fluid phases.
7. What triggers vibration.
8. Walkdown and photo pipe-supports.
9. Damage to Supports.
10. Video of movement.
11. Observed vibration, damage.
12. Vibration, damage history.
13. Recent mods as possible triggers.
14. Comp. maintenance records.
15. Opinions.

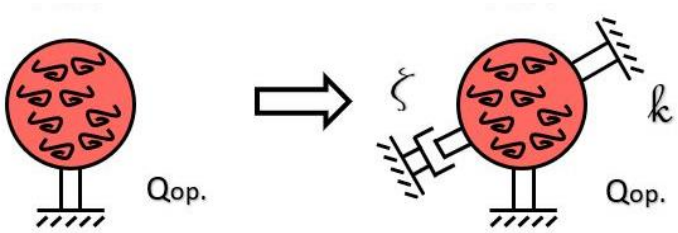


Step-3 Select Strategy

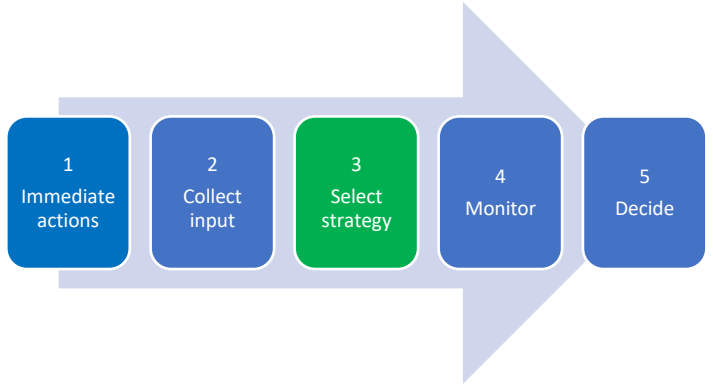
Tackle the hydraulics



Tackle the structure



Tackle both



Step-3 Sources of Excitation

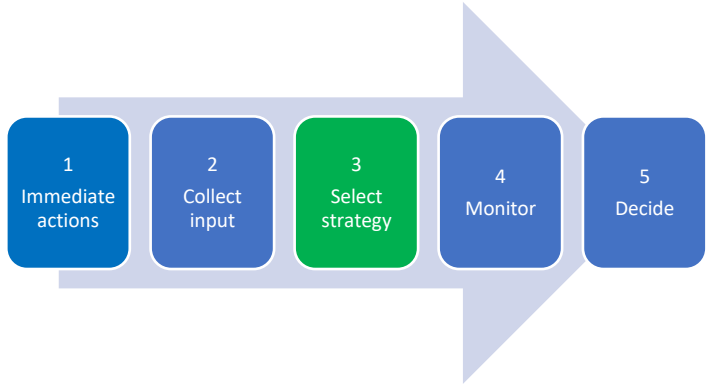
Flow-induced excitation (FIV)

Periodic

1. Pressure pulsing
   Vane (Piston) passing frequency
2. Vortex shedding
   Orifice plates, control valves, sharp branch openings, etc.

Broad band (random)

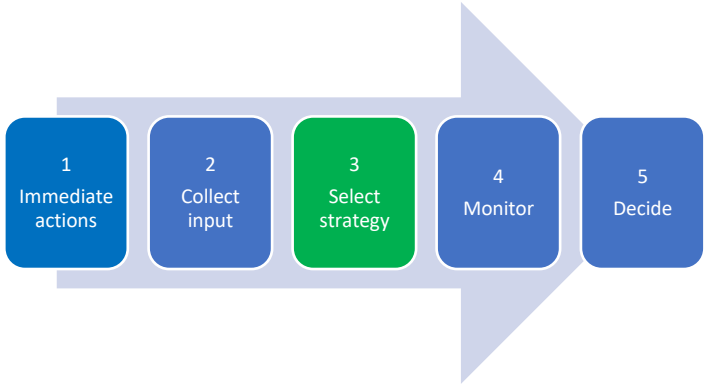
3. Excessive turbulence
   Kinetic energy of the fluid
4. Acoustic energy (AIV)
   High frequency sound
5. Cavitation
   Vaporization of liquid (control valves, orifices, etc.)
6. Two-phase flow
   Slug flow, plug flow, stratified flow, etc.



Step-3 Sources of Excitation

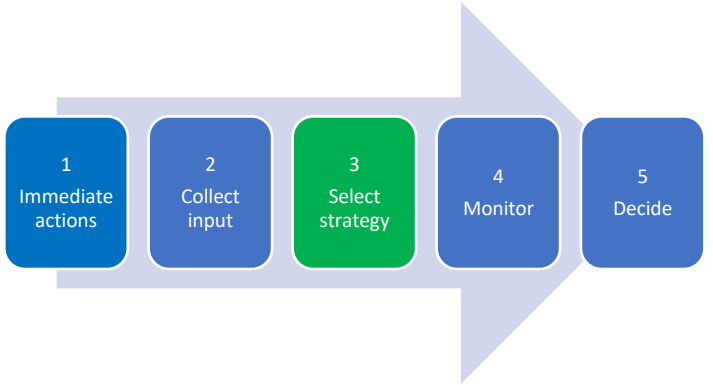
Mechanically-induced excitation

7. Small bore connection (SBC)
   Header is flow-induced FIV, in turn mechanically drives the SBC
8. Through machinery skid or foundation
9. Through machinery nozzle
   Pump or compressor vibrate, attached piping follows
10. Pressure vessel movement from fluid bed movement (FCC/Fluid Cokers)



Step-3 Sources of Excitation

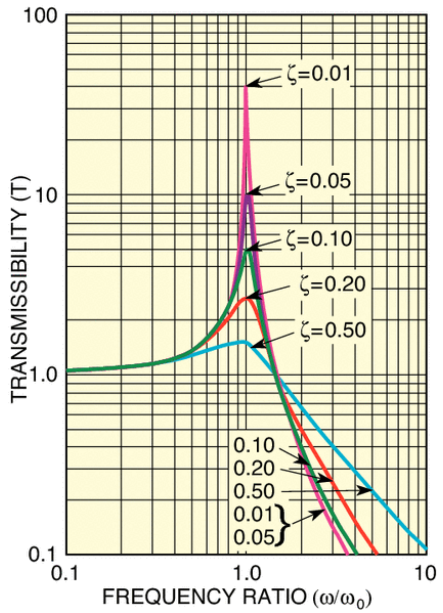
	Mech. or Flow-Induced Excitation	UK Energy Institute Guide Section Number
1	Pressure pulsing	T2.4, T2.5
2	Vortex shedding	T2.6
3	High turbulence	T2.2
4	Acoustic-induced	T2.7
5	Cavitation	T2.9
6	Two-phase steady	“Specialist advice”
7	Through header	T3, Ap.C
8	Through nozzle	T2.3
9	Through structure	T2.3



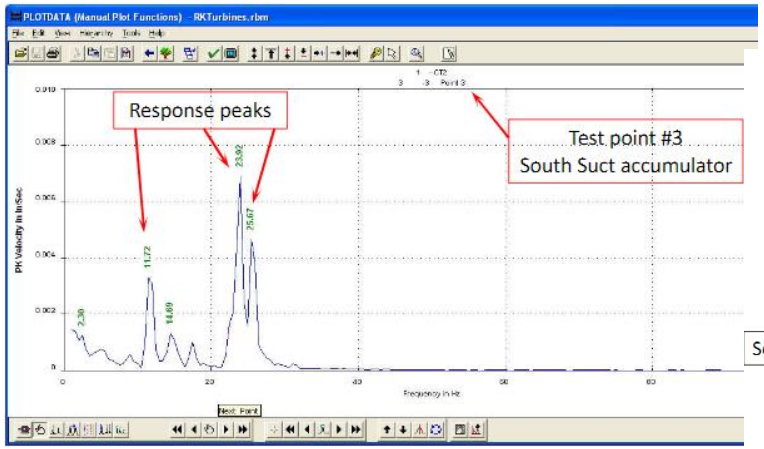
Step-3 The Role of Resonance

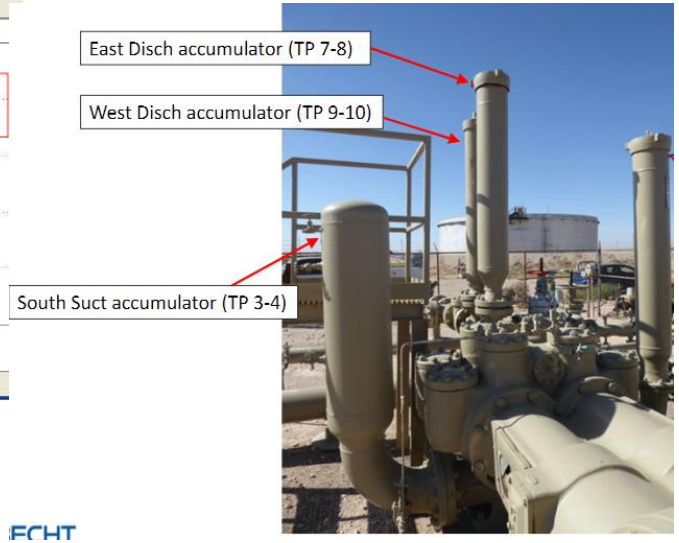
The role of resonance

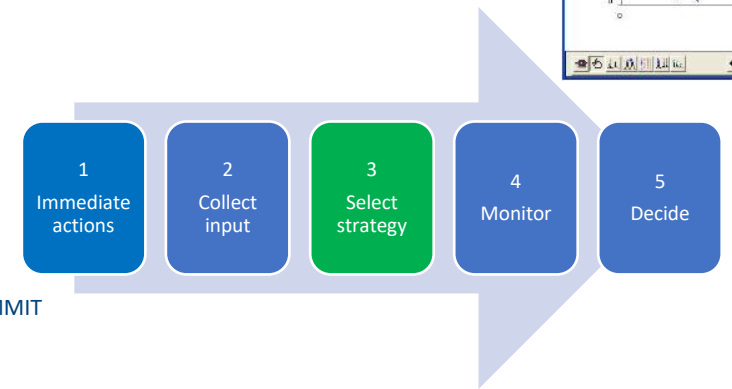
Vibration without resonance	☹
Vibration with structural resonance	☹☹☹
Vibration with acoustic resonance	☹☹☹
Vibration with structural and acoustic resonance	☹☹☹☹☹☹



Detecting Multiple Resonances



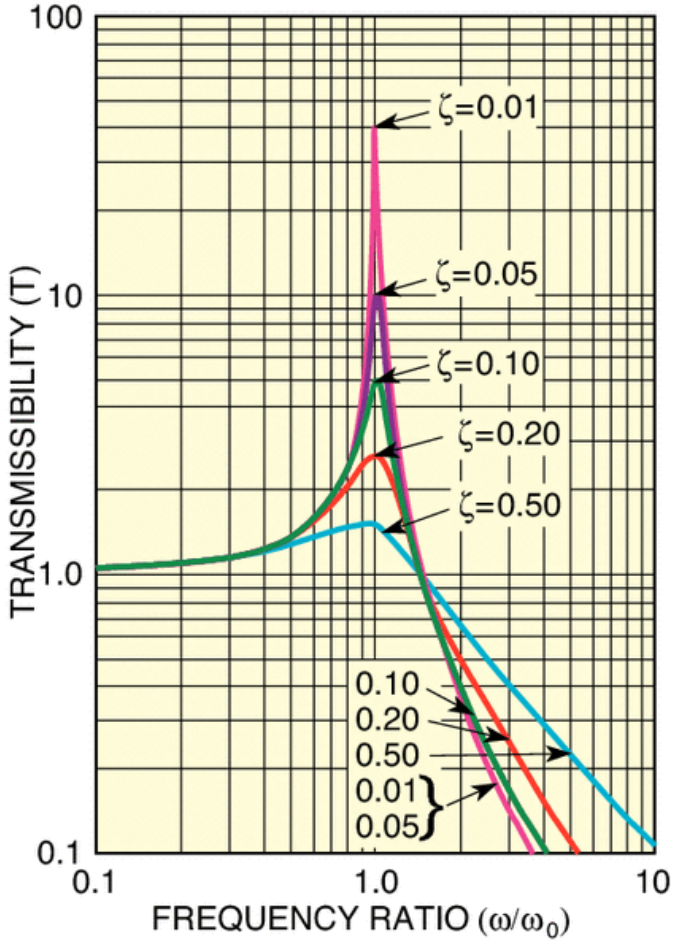


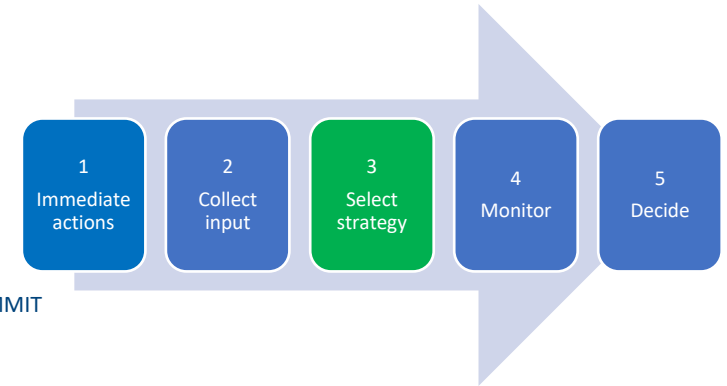


Step-3 The Role of Stiffness

Structural resonance of a rigid system amplifies small vibratory amplitudes (F/k_{rigid}).

Structural resonance of a flexible system amplifies large vibratory amplitudes ($F/k_{flexible}$).





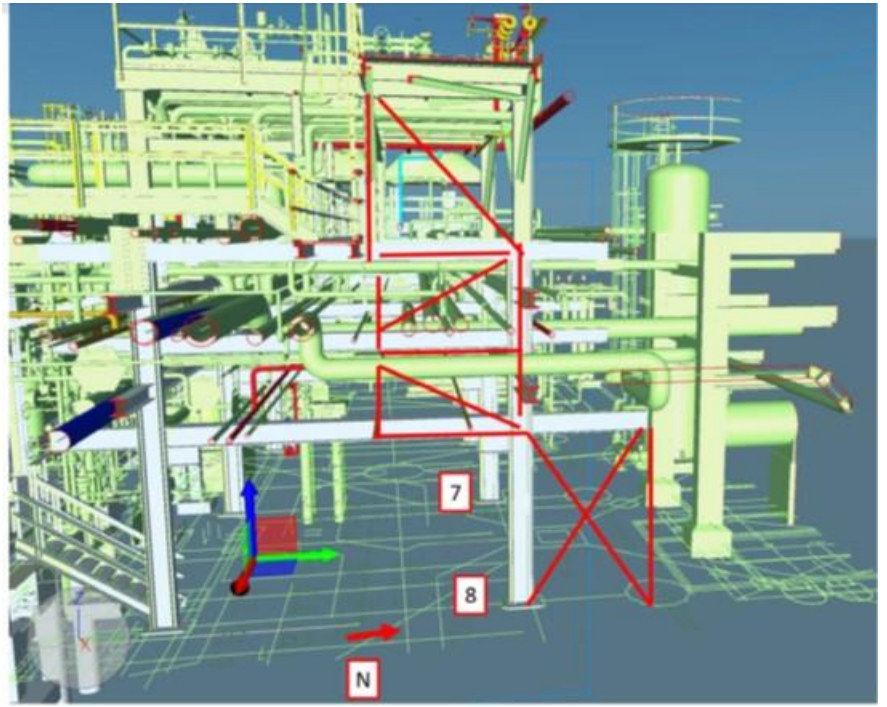
Step-3 The Role of Stiffness

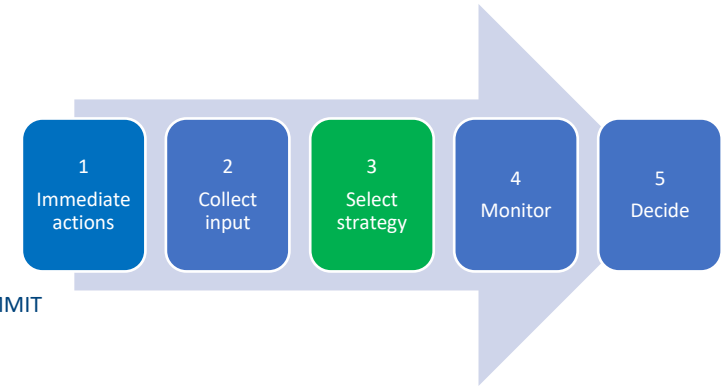
The role of stiffness

- Avoid excessively flexible pipe
- Avoid excessively flexible supports / racks
- Supporting Structure should be at least twice (2x) the stiffness of the piping system

Example

- Significant piping and rack vibration
- Diagonal bracing added to stiffen the structure

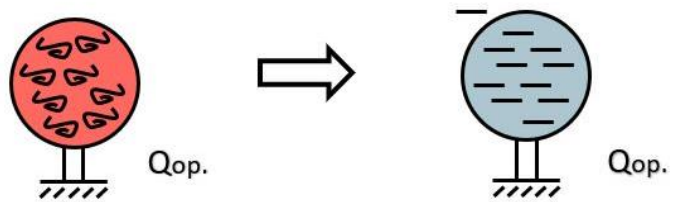




Step-4 Monitoring

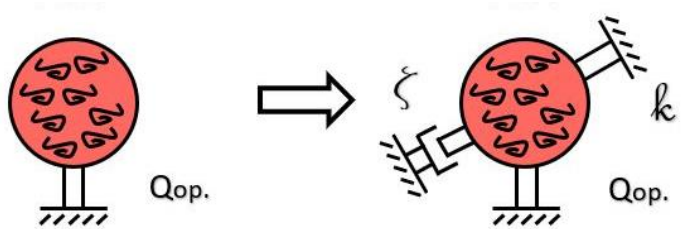
Monitor the hydraulics

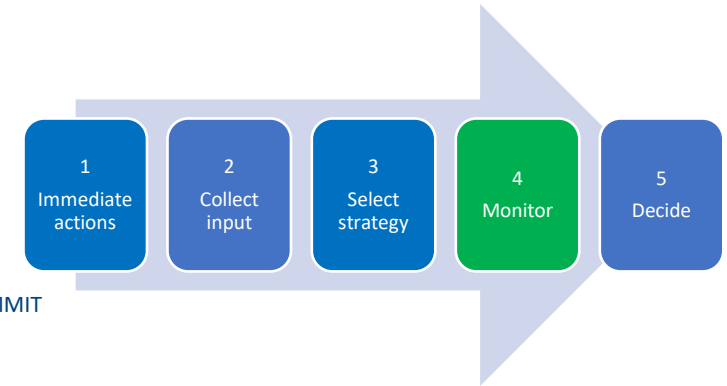
- Pressure (time, frequency domains)
- Flow rates (time, frequency domains)
- Microphone, strain gages (AIV)



Monitor the structure (the piping and supports)

- Accelerations, velocities, displacements
- Motion amplification

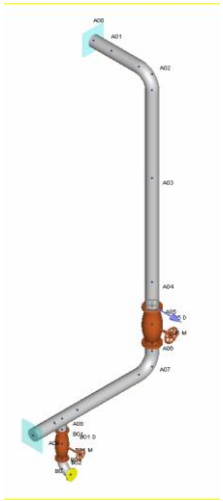


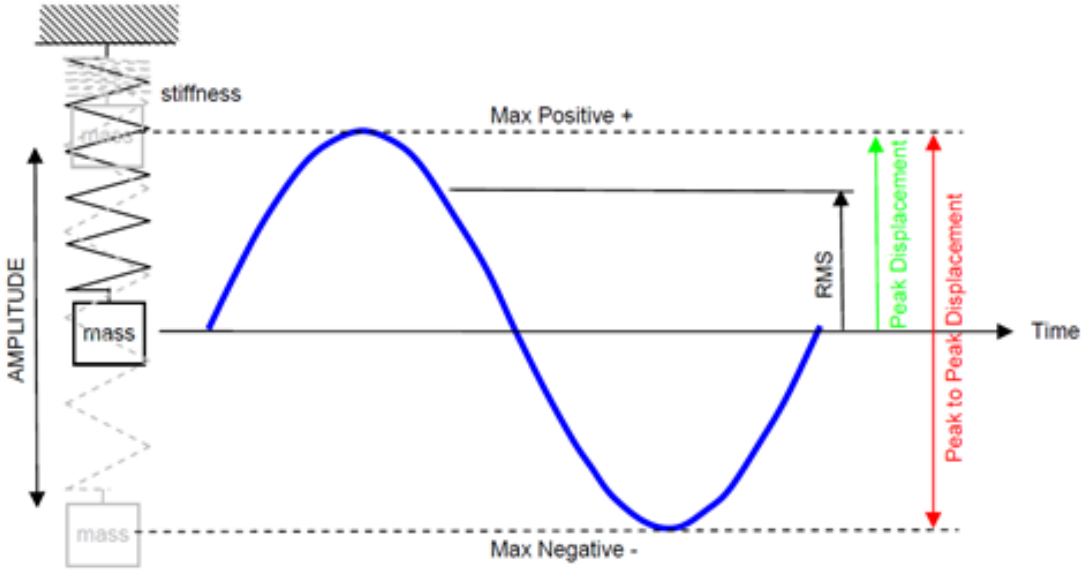


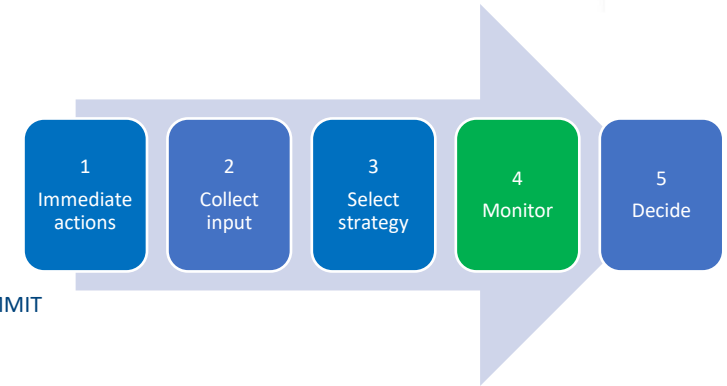
Step-4 Monitoring and Criteria

- ❑ Severity criteria
- Beam mode vibration
  - Three-Level approach
- Shell mode vibration

- ❑ Caution:
- Severity criteria in the form of
  - Peak-to-peak (range)
  - Amplitude (half range)
  - Root mean square (RMS)







Step-4 Monitoring and Criteria

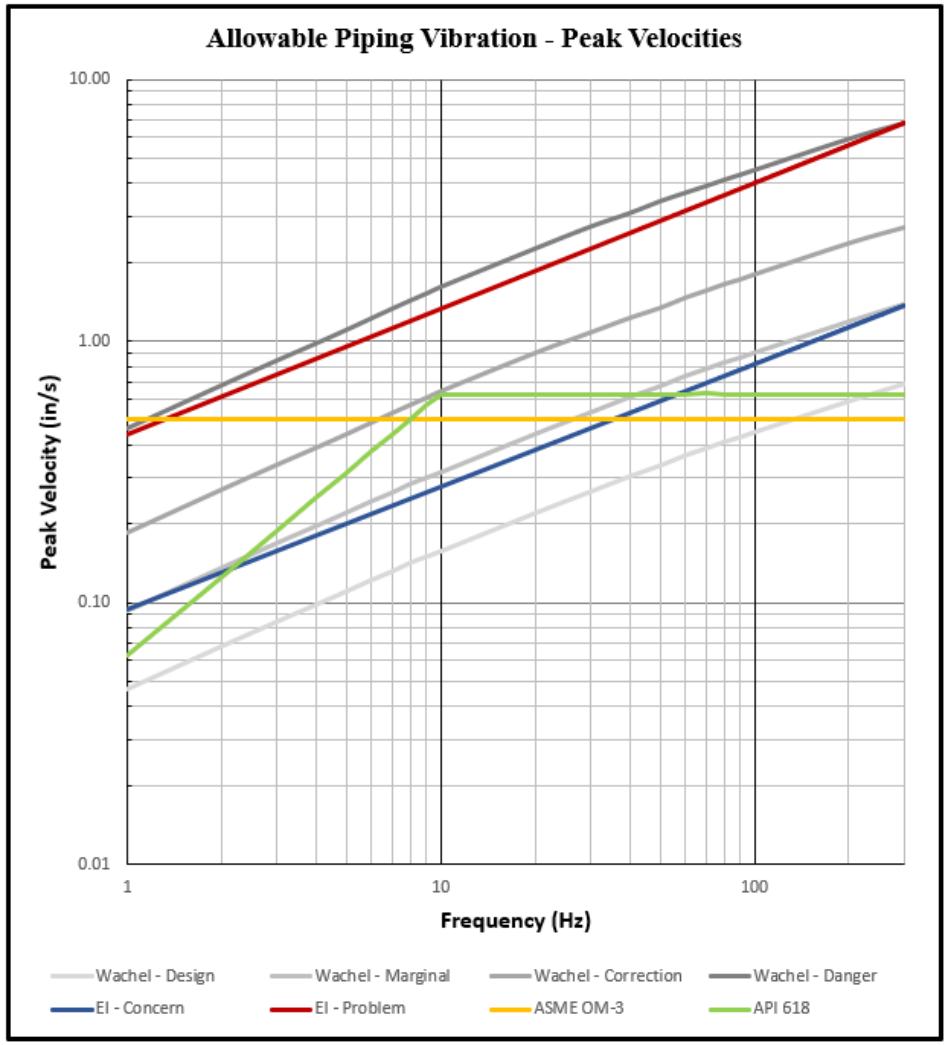
Beam mode vibration

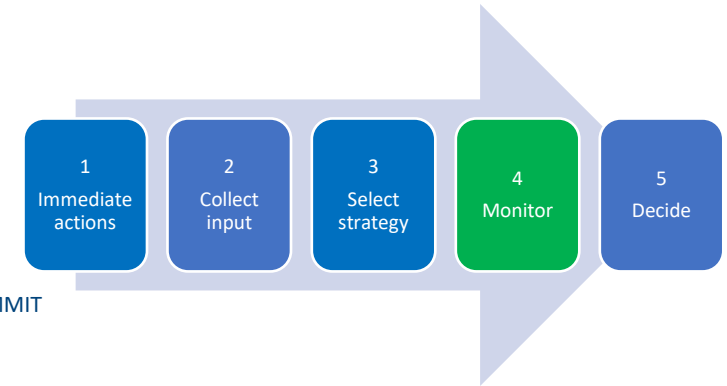
Level 1 velocity-based limits (API, ASME O&M Part 3, etc.)

- ASME O&M Nuclear Part 3
  - 0.5in/s – quite conservative
- API 618
- Wachel papers
- Energy Institute

Level 2 ASME B31 pipe stress-based limits

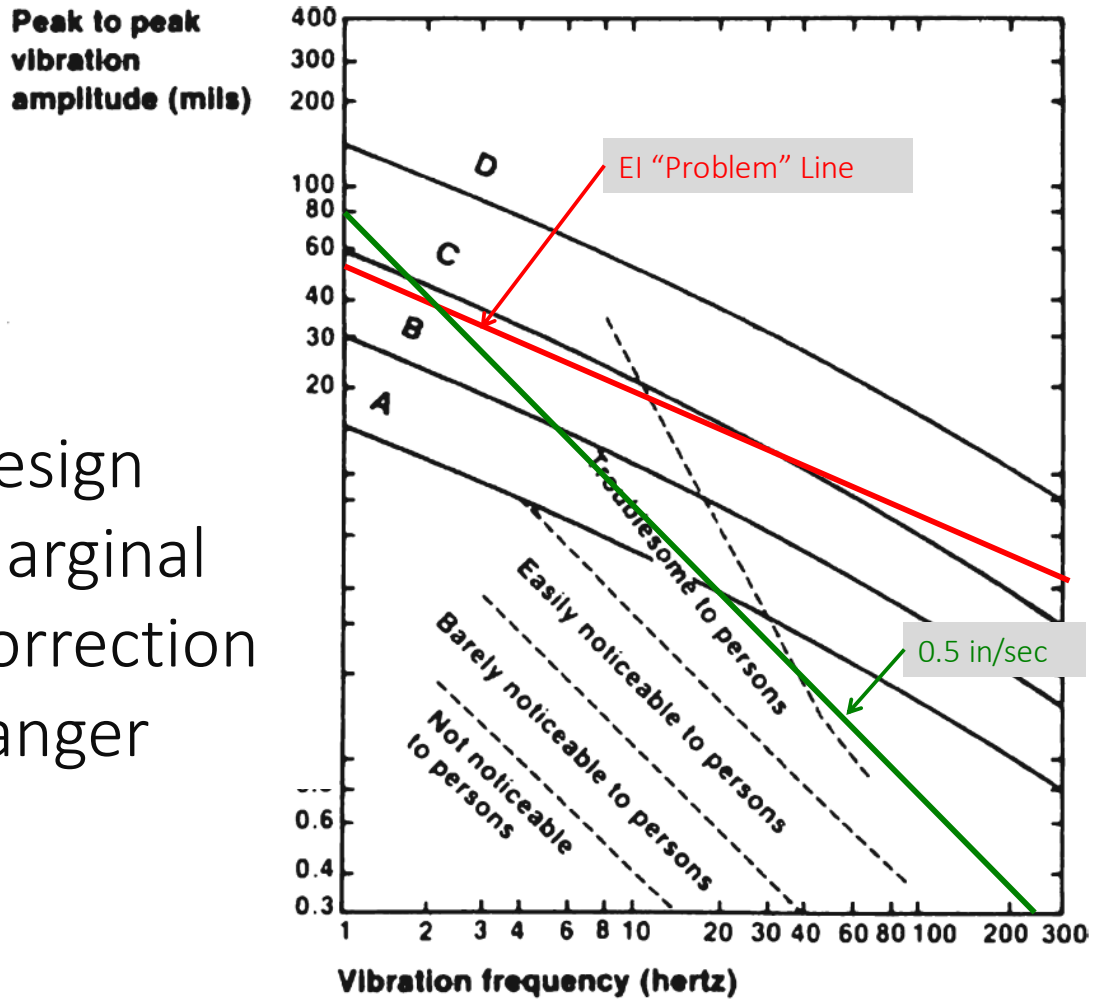
Level 3 ASME VIII Div.2 detailed stress-strain limits



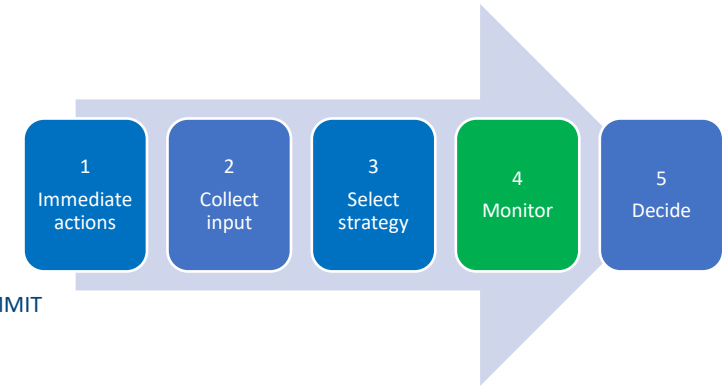


Step-4 Monitoring and Criteria

- Level 1 displacement based
  - Olson D., *Piping Vibration Experience in Power Plants*, ASME Pressure Vessel and Piping Technology, A decade of progress - 1985

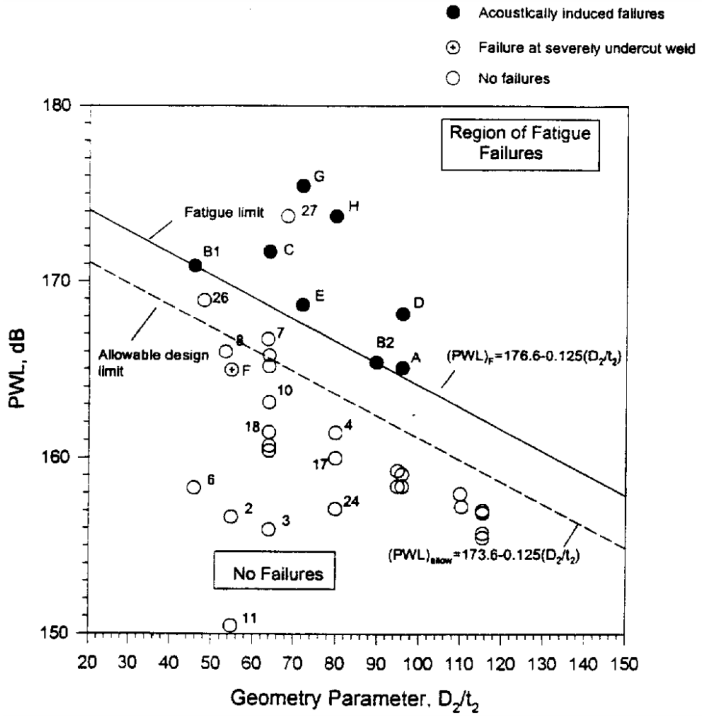


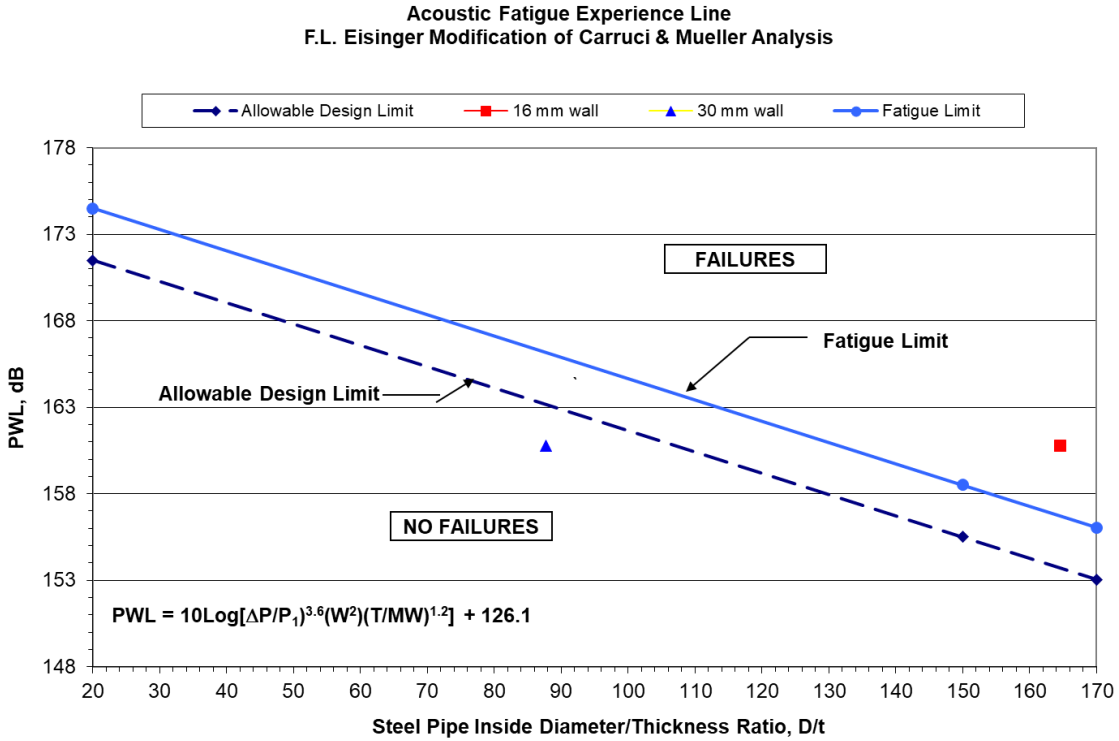
A – Design
B – Marginal
C – Correction
D - Danger

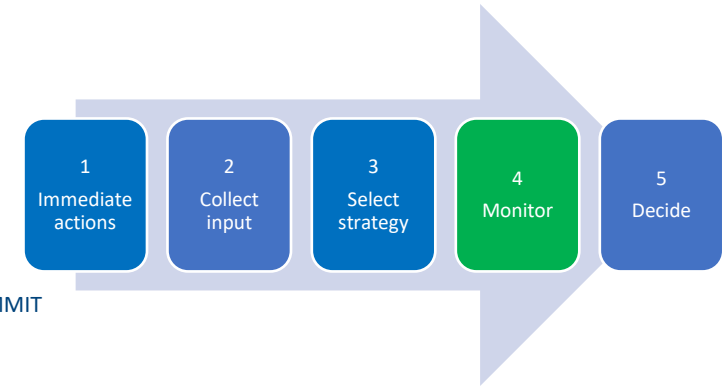


Step-4 Monitoring and Criteria

Shell mode vibration



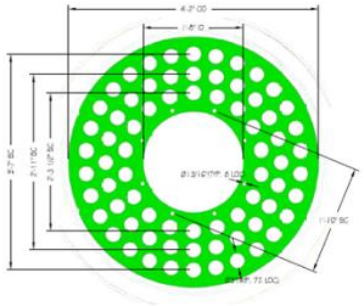


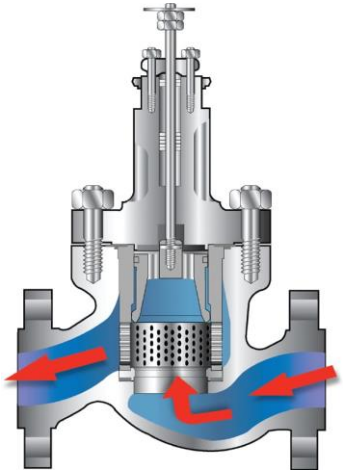


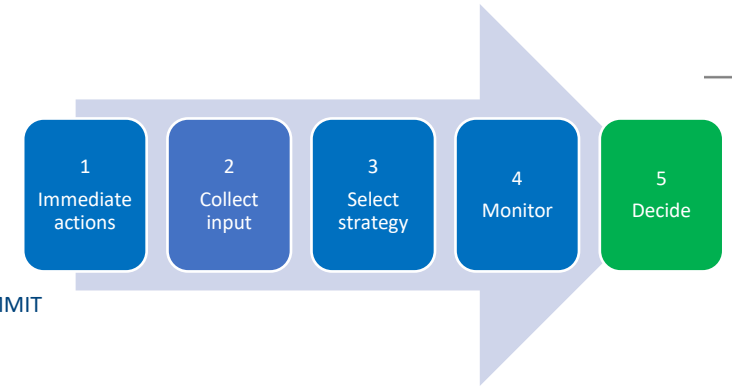
Step-5 Decide (Hydraulic)

Optimize the **hydraulics**

- Improve hydraulics
  - System hydraulic sizing review
  - Component (valve, orifice) sizing review
  - Improved valve trim (labyrinth trim)
  - Multi-plate orifice
  - Pulsation bottles
  - Smooth mixing point configurations
  - Slug catcher
- Modify flow rate and flow regime
- Eliminate acoustic resonance







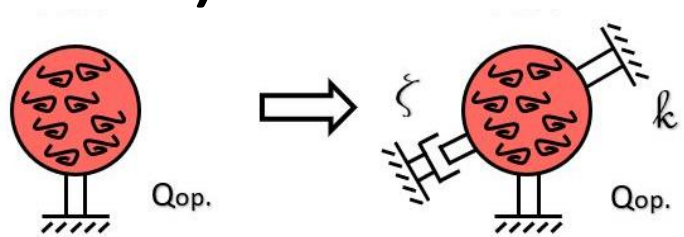
Step-5 Decide (structure)

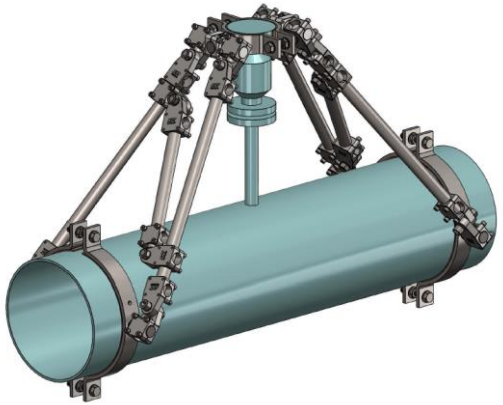
Optimize the **structure**

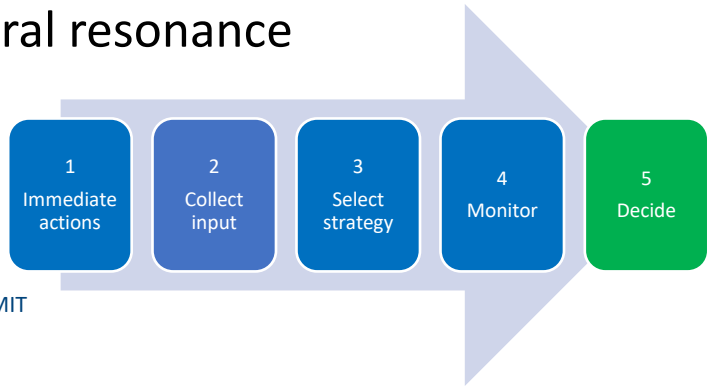
- Stiffening
  - Restore damaged supports, restraints
  - Add supports and restraints
  - Stiffen supporting structure
  - Add gussets to small bore connections (tie-backs)
  - Smooth weld profile and structural discontinuities
  - Clamp
- Damping
  - Add anti-vibration pads
  - Add dampers

  (damper photo source: Gerb)

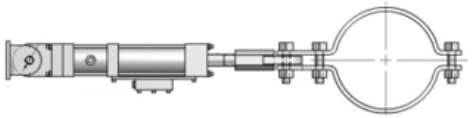
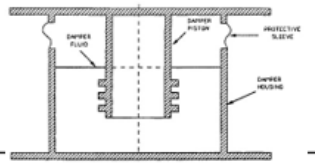
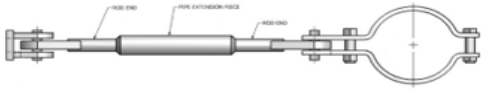
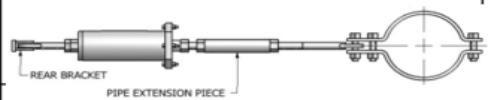
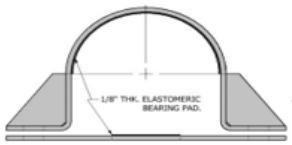
  (wire energy absorber photo source: ENIDINE)
- Eliminate structural resonance

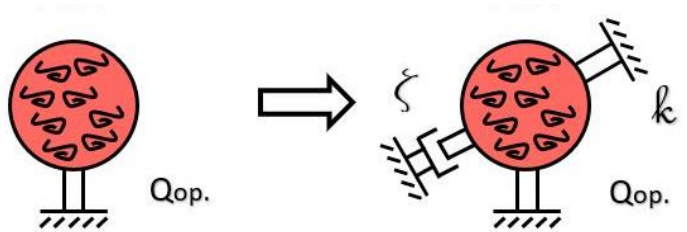






Step-5 Decide (Structure)

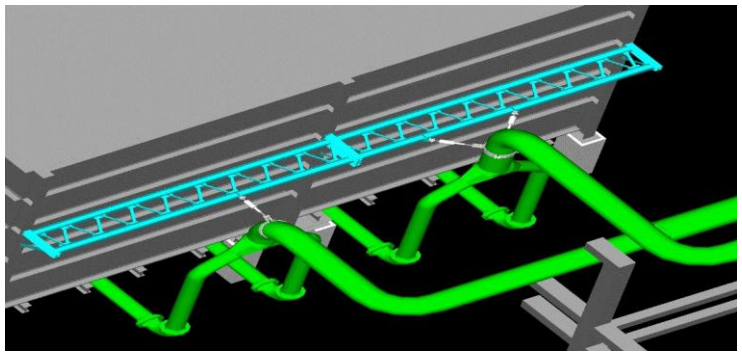
Snubber	Restrains rapid movement • Hydraulic • Mechanical	
Viscous Damper	Dampens movement	
Sway Strut	Rigidly restrains lateral movement	
Sway Brace	Restrains movement below a threshold force	
Friction Restraint	Restrains movement below a threshold force	

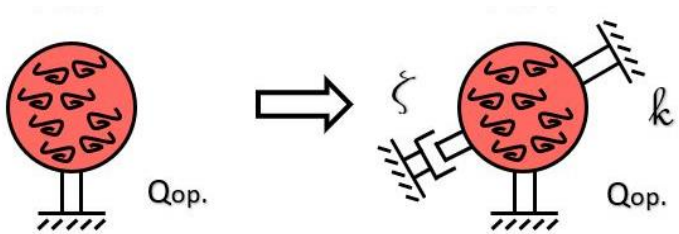


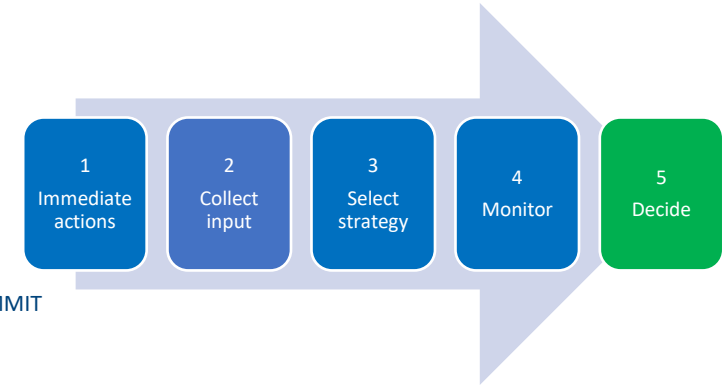
1 Immediate actions → 2 Collect input → 3 Select strategy → 4 Monitor → 5 Decide

Step-5 Decide (Structure)

- 30” diameter outlet from Vacuum Pipestill heater (two-phase flow), displacing over ~1”.
  - Identify the motion
  - Quantify the vibration
  - Restrain the movement

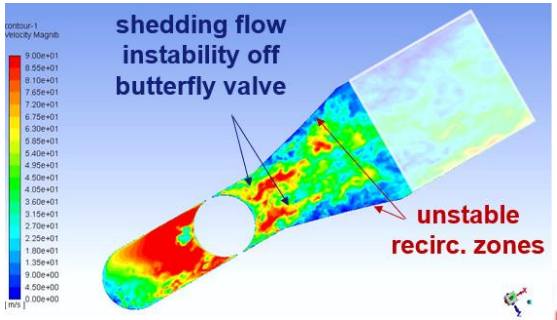


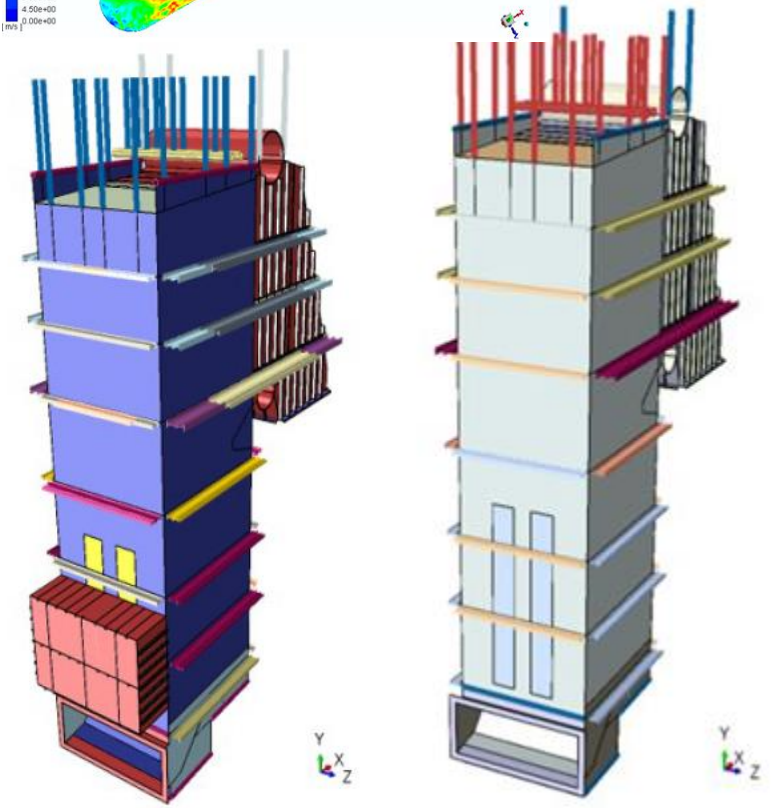


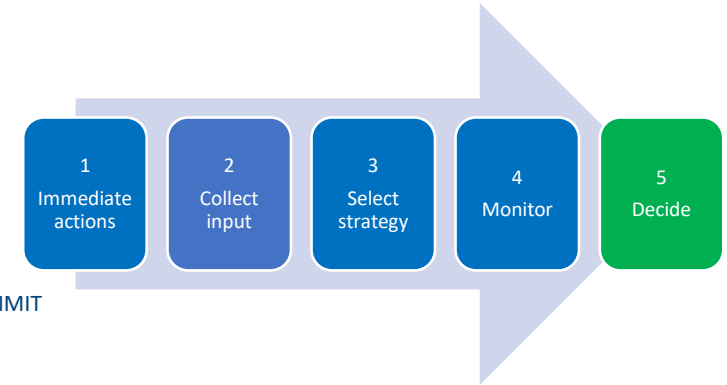


Step-5 Decide (Both)

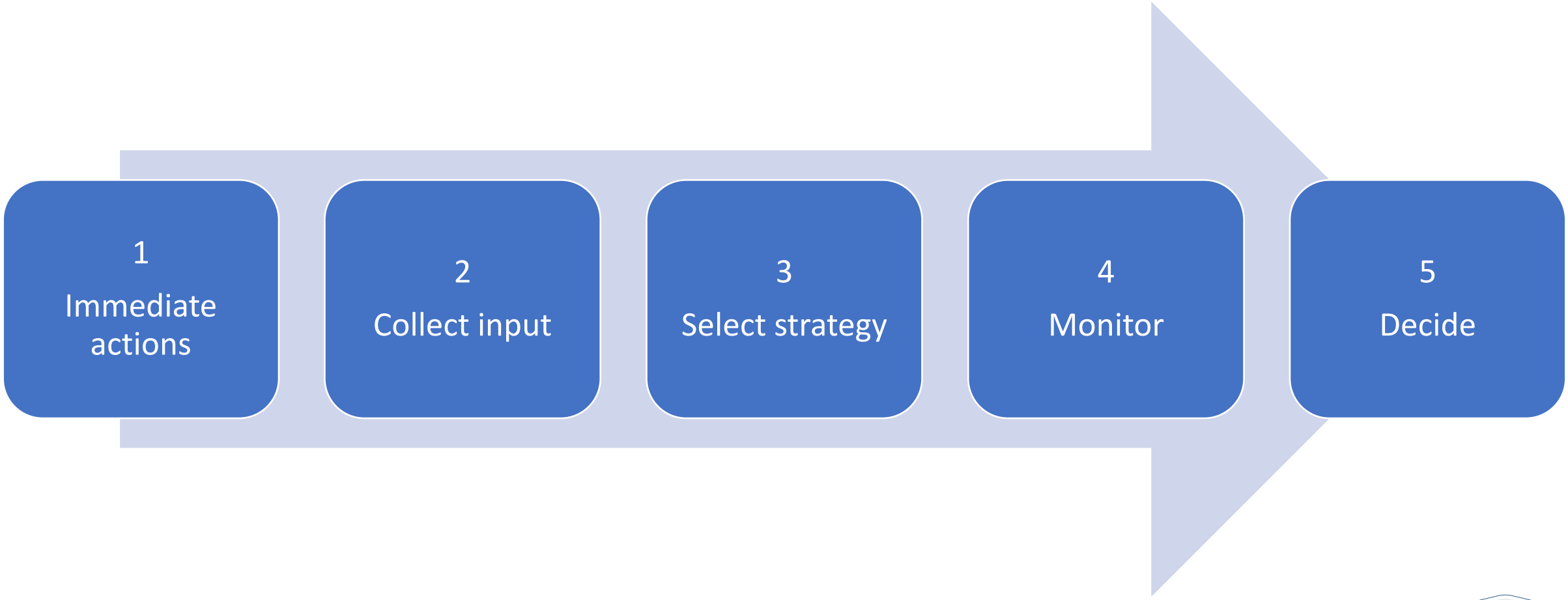
- The boiler of a fluidized catalytic cracking unit (FCCU) combusts CO.
- After 20 years of operation converted to a waste heat boiler.
- 10 years after conversion, the boiler was replaced “in kind”.
- Upon startup the new “in kind” boiler vibrated so violently that FCCU capacity had to be reduced.
- In fact, the “in kind” modification was not in kind. The previous burners had been removed, changing the structural characteristic of the side wall. The stiffnesses and masses (**dynamic characteristics**) had been modified.
- CFD and FEA simulation, with fluid-structure interaction, and boiler structural expertise identified (a) the flow and (b) the structural modifications (stiffening) necessary to stop the vibration.







Conclusion


1
Immediate actions
2
Collect input
3
Select strategy
4
Monitor
5
Decide