BETA MACHINERY ANALYSIS

Piping Vibration Risks and Integrity Assessment

Piping systems are subject to vibration induced failures. To mitigate this integrity risk, a piping vibration assessment is conducted during the design phase and high risk locations are tested during operation. This article highlights the vibration risks and assessment approaches.

Background

Piping vibration problems are a reality at onshore or offshore production facilities, pipeline stations, refineries, and petrochemical plants. Facility owners are extremely sensitive to these integrity risks because of the significant consequences associated with product releases from ruptured piping. Recent examples in the press highlight situations where piping failures caused explosions, loss of life, environmental damage due to onshore and offshore spills, lawsuits, and facility shutdowns.

Figure 1: Severe safety and environmental consequences of piping fatigue failures.

Vibration can cause reliability problems on equipment, fatigue failure on process piping, and small branch connections including relief lines, instrumentation ports, nozzles, drains, and valves. Vibration on rotating machinery is also a reliability issue, but is addressed in separate scopes of work (refer to www.BetaMachinery.com for more information).

This article provides advice for owners planning to implement a **Piping Vibration and Integrity Assessment** (also referred to as a Piping Vibration Audit). This service is based on the Energy Institute 2008 *Guideline for the avoidance of vibration induced fatigue failure in process pipework* (AVIFF).

Piping Risks in Onshore and Offshore Facilities

Gas Plants, Refineries, Pipelines, Pumping and Compressor Stations

There are a number of common piping risks to be evaluated in a piping assessment:

- Small bore connections (SBCs) and branch attachments connect to the main process piping. These small attachments, typically less than 8 cm (3 inches) in diameter, are the most common cause of integrity problems. Even if the main process piping has acceptable vibration, the vibration can be amplified on SBC causing failures. For large facilities there can be thousands of SBCs that pose this integrity risk.
- Process piping vibration can cause excessive vibratory stress on nozzles and tees leading to cracks.
- Failure of bypass lines, PSV or relief lines.
- Transient related events such as starting, stopping, emergency shutdown, or closing and opening valves can cause momentum changes in the gas or liquid (fluid hammer), resulting is excessive stress.
- Fretting and damage to pipe supports.
- Structural resonance on overhead pipe racks.
- Pipe stress analysis can be in conflict with vibration design requirements. Unless the design resolves the conflict between Mechanical Vibration Design (adding stiffness to control vibration) and the Piping Stress Analysis (increasing flexibility for thermal analysis), there are risks that the piping system will experience stress failures.

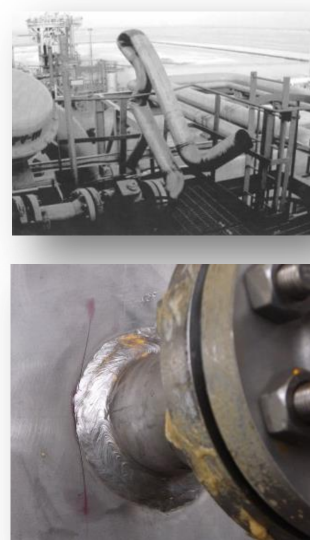

Figure 2: Piping failure examples

Causes of Piping Integrity Issues on Offshore Platforms or FPSOs

In addition to the above risks, offshore facilities have increased piping vibration challenges:

- Space on an offshore production facility is limited and the piping layout is often very compact. As shown in Figure 3 the tight layout creates unique challenges in controlling piping vibration.
- The piping system is often elevated, connecting rotating machinery to overhead coolers, vessels, or headers. Elevated piping is more typically much more flexible than rigidly connected or buried piping because of the difficulties in designing sufficiently stiff piping supports (that prevent vibration).
- Safety requirements often require “double block and bleed” valves on many small bore connections. The geometry of these valve configurations and the heavy overhung weight creates much higher chances of excessive stress and failure.

Figure 3 example of compact piping layout on an FPSO

Vibration (Excitation) Sources

Piping vibration is caused by these excitation sources (see Table 1, below). The type, frequency, and amplitude of the force will determine the likelihood of failure (LOF) due to induced vibration.

Table 1

Excitation Force	Description
Pulsations - Reciprocating Compressor or Pump	Pulsations created by the piston motion and valve opening and closing
Pulsations - Centrifugal Compressor or Pump at Vane Passing Frequency	Pulsations created when impeller vanes pass the volute edge
Pulsations - Screw Compressor or Pump at Pocket Passing Frequency	Pulsations created when each pocket of gas is released
Flow Induced Turbulence (FIT)	Energy created by turbulent fluid flow
Flow Induced Excitation or Vibration (FIE or FIV)	Gas flow past a deadleg or over an object in the flow (e.g., a thermowell) causing vortices to be shed at specific frequencies
Acoustic Induced Excitation or Vibration (AIE or AIV)	High frequency acoustic energy generated in gas systems by a pressure reducing device such as a relief valve, control valve or orifice plate
Water Hammer - Valve Opening and Closing	Pressure wave caused by the kinetic energy of a liquid in motion when it is forced to stop or change direction suddenly
Momentum Change - Valve Opening	Pressure wave in the gas system caused by the sudden opening of valve, like a PSV
Cavitation/Flashing	Sudden formation and collapse of bubbles inside a liquid that can occur at localized pressure drop (e.g., at centrifugal pumps, valves, orifice plates)
Machinery Unbalanced Forces and Moments	Unbalance created by rotating equipment
Crosshead Guide Forces	Forces created when converting rotating motion into reciprocating motion
Cylinder Stretching Forces	Forces created due to pressure inside compressor cylinder or pump plunger
Temperature and Pressure Differential	Loads on piping, restraints, equipment, and machinery created by changes in temperature and pressure
Bolt-up Strain	Load created by offset and misalignment between bolted connections like flanges and clamps
Lifting	Loads on equipment and machinery baseplate due to lifting
Environmental Loads	Loads on equipment and machinery baseplate due to transportation, seismic shifts, wind, etc.
Machinery Mean Torque	Static loads on machinery, piping, and foundation due to mean torque
Machinery Alternating Torque	Dynamic loads on machinery, piping, and foundation due to alternating torque

Piping Vibration Assessment - Methodology

BETA recommends following the Energy Institute (EI) Guideline[1] as the high level screening methodology since it has a rigorous and systematic process to address the main vibration risks. The assessment investigates both the main process piping and SBC. Both transient and steady state conditions should be included in the Piping Vibration and Integrity Assessment.

BETA has augmented the EI Guideline to provide superior integrity during the design and field testing phase. These additional features are based on our experience in evaluating piping vibration over the past 45 years.

Recommended Approach: Piping Vibration Integrity Assessment for New Project or Existing Facility

Front End Engineering Design (FEED) Stage A Vibration Design Review is recommended for the piping design and machinery systems (including proposed skids and foundation plan). This review provides valuable input to the vibration control strategies, required engineering tasks, and input to improve the design process. Deliverables include recommendations for scope of vibration engineering and dynamics, methodology, guidelines, required scheduling and design considerations.

To ensure an integrated vibration design, the scope should include the piping and support systems for reciprocating compressors and pumps, centrifugal compressors and pumps, and the foundation or structural supports.

Detailed Design Stage The scope of work will include:

1. Assessment of piping system and identify locations having high Likelihood of Failure (LOF) per Energy Institute approach
2. Evaluate design standards for SBC and piping support assumptions for dynamic loads
3. Provide recommendations to reduce integrity risks
4. Implement specialized analysis where required (e.g., FIV, AIV, pulsation analysis, transient studies)
5. Calculate allowable vibration limits at high LOF SBCs.
6. Integrate the vibration analysis with other aspects of the project, namely reciprocating equipment, piping systems on centrifugal equipment, and dynamic analysis of foundations and structure where appropriate.
7. Prepare test plan for field baseline measurements (re: commissioning and operations phase).

During Commissioning and Operation

1. Conduct a baseline vibration survey during operation to verify vibration levels. Measure mechanical natural frequencies (MNFs) of small bore connections, inspect pipe supports for pipe strain and alignment, and conduct transient vibration testing where required
2. Remedy remaining issues with recommendations and further troubleshooting, if required

Study Requirements

Appropriate tools and expertise in the following areas are necessary to properly perform this assessment:

- Specialized field measurement instrumentation to properly capture transient vibration across many channels and operating conditions. Single channel vibration equipment is not sufficient to capture vibrations during changes in operating conditions. For many facilities, a multi-channel data acquisition system comprising 120 channels is required.

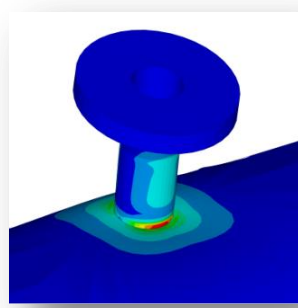

Figure 4: Finite element analysis (FEA) used to calculate stress on

- Advanced data processing techniques and software tools to analyze the data library, including time waveform and frequency based results. The post processing will determine locations of excess vibration, stress, and the impact on integrity.

- Experience in troubleshooting. The vibration/dynamic engineering company should have 20+ years' experience in piping and machinery troubleshooting to assist in root cause analysis. Detailed experience in identifying and resolving FIE/FIV, AIE/AIV, surge, resonance, shell mode, and pulsation problems in the field and during the design stage.

- Engineering experience with designing effective vibration solutions for compressors and pump systems. This includes detailed design and field experience with pulsation analysis, mechanical forced response, dynamic pressure drop, blowdown studies, and other related work.

- Experience in dynamic analysis. When high risk areas (high LOF) are identified, the project team will need to investigate the problem in more detail using advanced modeling simulations such as pulsation analysis (or acoustic analysis), modal analysis, FEA, transient analysis, surge control simulation, or other studies.

Figure 5: Piping Vibration Assessment (including small bore piping during normal and transient operations)

- Ability to interpret and apply vibration and stress guidelines. This is a confusing area due to many different test methodologies, guidelines, and international standards that may apply.

- Proper documentation and effective project management. The integrity assessment must include the work processes, as well as related information databases to document all test locations, measurements, problem areas, approved modifications, issue status, and compliance.

Given the above requirements, facility owners and operators typically employ a specialized vibration and dynamic engineering company, such as BETA, to assist in the piping review, assessment, and field surveys.

BETA's Capabilities

BETA has unique experience and skills in piping vibration, including the assessment of large scale piping projects. For nearly 50 years, the Company has pioneered vibration analysis on machines and piping systems and is recognized as a global leader in this field.

Figure 6: BETA site testing program includes multi-channel data

Capabilities include:

- Experience on a wide range of piping systems, including refineries, petrochemical plants, pipeline stations, water injection units, and offshore platforms and FPSOs

- Screening evaluation techniques to assess process piping and attached small bore piping connections including cost-effective methods to determine if vibration induced failure will occur

- Implementation of major projects involving the Energy Institute Guideline and other applicable approaches and guidelines

- Proprietary and field verified software tools to accurately model piping systems, assess vibration and stress, and evaluate the effectiveness of proposed modifications. Field proven tools and techniques are key success factors. Many examples exist where inexperience and standard FEA software do not produce accurate results.

- Involvement in three different large scale projects with international research organizations, such as the Gas Machinery Research Council, aimed at finding solutions to piping and machine vibration

- Development of custom designed products to address high risk vibration areas

- Consulting expertise in piping design, small bore piping evaluation, root cause analysis, troubleshooting, and the specialized analysis needed to tackle high risk problems[3].

Summary

To address the piping integrity risk due to vibration, many facility operators are implementing the Piping Vibration and Integrity Assessment (piping vibration audit). Avoiding these risks has many benefits to employees, managers, operations staff, shareholders, and society as a whole. Such benefits include:

- Increased safety
- Reduced environmental risk
- Increased uptime for operations
- Reduced unplanned downtime and failures
- More accurate integrity data for the Integrity Management System
- Overall reduced operating risk

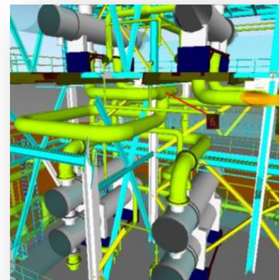

Figure 7 Example of Piping Vibration Assessment at a refinery, including troubleshooting support

References

1. Energy Institute Guideline, 2008, Guidelines for the avoidance of vibration induced fatigue failure in process pipework, 2nd ed. Jan 2008 978–0–85293–463–0
2. Small Bore Piping Failures on the Rise, CompressorTech2 magazine, March 2012, www.betamachinery.com/wiki/technical-articles
3. Vibration Related Failures of Small Bore Attachments, Beta Machinery Analysis, Brian Howes and Chris Harper, www.betamachinery.com/wiki/technical-articles