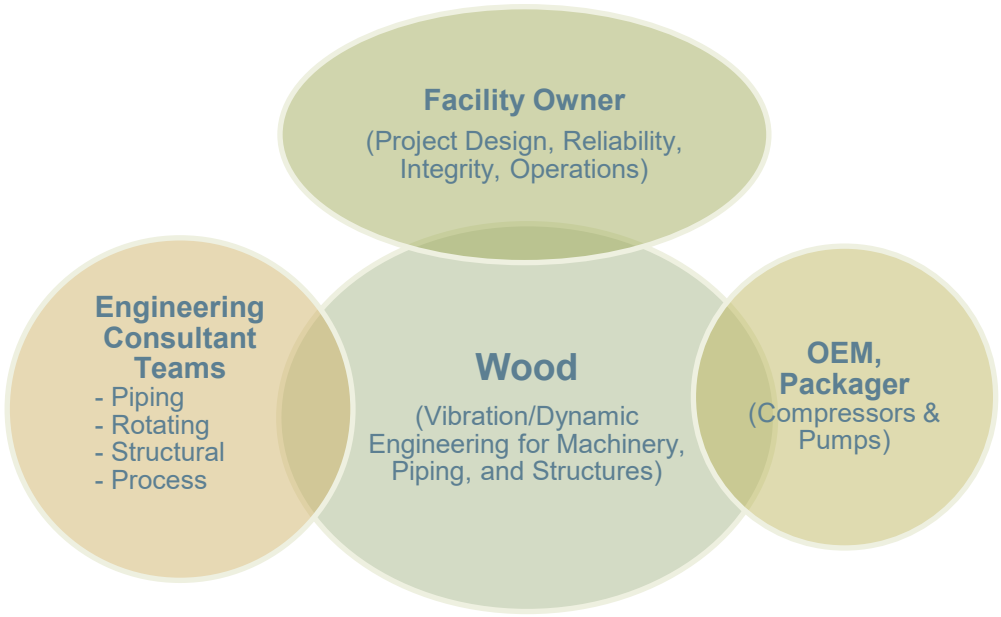
Specification for facility-wide vibration design requirements – greenfield and brownfield projects

Background

Vibration-related reliability and integrity problems exist on onshore and offshore production facilities. To manage these risks, the appropriate engineering work is required at the design stage. This document identifies which activities are required for rotating/reciprocating machines and for the overall piping system. The recommended scope will vary based on the type of facility (e.g., refinery, offshore platform, pipeline station, upstream oil or gas facility).

Wood works directly with the owner during the FEED/planning stage to recommend the engineering scope and options, piping/machinery layout ideas, and design approaches. This ensures the vibration design is aligned with the owner's operational, reliability, and integrity requirements.

The engineering work must be integrated with other team members (owner, EPC teams, OEMs, and packagers). The chart below illustrates Wood's role in delivering an integrating vibration solution.



Goal

Achieve the organisation's reliability and integrity goals for the production facility, including the mitigation of vibration and dynamic issues on platform structures, machinery, and piping system.

Approach

An integrated and coordinated approach is required to manage vibration. This approach ensures the appropriate scope of work is conducted at the right time and involves input and review by the necessary stakeholders. Refer to Wood's article, An Integrated Approach to Manage Vibrations Risks, available as a pdf download on our website, vibration, dynamics and noise website.

The following scope outlines typical vibration studies (or analysis) required for a production facility. Not all of these studies are required on every facility. The scope will depend on the facility's location (onshore or offshore), flow rates, application, and other risk factors. Wood's role is to help owners/EPCs define the necessary scope of work for their project. For application questions, contact us at info.vdn@woodplc.com.

To ensure consistency and avoid conflicting results, the work should be performed by the same vibration engineering firm.

Vibration control studies for production facilities

<table>
<tr><th>Compressor systems</th><th>Pump systems</th><th>Piping systems</th></tr>
<tr><td>Centrifugal compressors
✓ Surge control design (dynamic simulation)
✓ Flow-induced vibration (FIV)
✓ Acoustic-induced vibration (AIV)
✓ Rotor dynamics
Reciprocating compressors
✓ API 618 (or GMRC Guideline) Pulsation and Mechanical Analysis including Forced Response Study
✓ Torsional vibration
✓ Small bore connections (SBC)
✓ Skid dynamics
Screw Compressors
✓ Shell mode (oil flooded)
✓ Silencer acoustics (dry screws)
✓ Pipe stress (thermal)</td><td>Centrifugal pumps
✓ Piping vibration (including small bore piping)
✓ Transient surge/water Hammer (pump startup, shutdown, valve closures, etc.)
✓ Pump Casing Finite Element Analysis (FEA) (Stress Analysis, Reed Critical Frequency)
Reciprocating pumps
✓ API 674 Pulsation and Mechanical Analysis including Forced Response Study
✓ Water hammer (liquid transients)</td><td rowspan="2">General piping vibration and stress
✓ Piping vibration and integrity (Energy Institute (EI) Guideline 2008, Avoidance of Vibration-induced Fatigue Failure (AVIFF))
✓ SBC
✓ Piping support design and vibration restraints
✓ Pipe stress (thermal)
Transient surge/water hammer
✓ Transient surge (water hammer, check valve slam, blow down, valve swing, emergency shutdown (ESD), etc.)
✓ Tank system transients
✓ Liquid system control optimisation
Advanced piping evaluations
✓ Shell mode/transverse acoustical (acoustical – piping interaction)
✓ Modal
✓ Cavitation from pressure reducing devices
✓ Flow-induced turbulence (FIT)
✓ Subsea piping vibration</td></tr>
<tr><td colspan="2">Other applicable requirements for compressor and pump systems (depending on the application)
✓ Foundation design and dynamics
✓ Skid and structural dynamics (offshore facilities or racks)
✓ Piping stress (thermal) (refer to the piping systems column)
✓ Station Assessment (interaction between centrifugal and reciprocating compressors)
✓ Torsional and rotor dynamics
✓ FEA</td></tr>
</table>

Overview of Design Requirements

For more detailed specifications for individual machine or piping assets, refer to our website, vibration, dynamics and noise website.

1. **Reciprocating compressors and pumps**

    a. Pulsation and Mechanical Analysis is for compressors (as per API 618 Design Approach 3 and GMRC High Speed Guideline) and pumps (API 674). Time Domain Acoustical Analysis is required for pulsation analysis. MAPAK is approved TD simulation software. Frequency domain simulation software packages are not acceptable. Mechanical Analysis must include frequency avoidance and forced response analysis using ANSYS software. Significant forces to be calculated and applied to the analysis include pulsation forces, cylinder gas forces, cross head forces, unbalanced forces, torsional to lateral forces, etc. Results are to be analyzed across all operating conditions and required frequencies, with results presented in summarized tables using post processing (DataMiner) reporting tools.

    b. Torsional Vibration Analysis must include all normal conditions, start-up, transient, upset, and conditions across the full speed range. Results are to be assessed using DataMiner software.

    c. Pipe Stress Analysis is often required for larger station/facilities.

    d. SBC Assessment is required.

    e. Skid Design and Analysis, Foundation Design and Dynamic Analysis, Lifting and Environmental Loading Analysis are required for reciprocating compressor packages.

2. **Centrifugal compressors – Surge Control Dynamic, FIV, and AIV Analysis**

    The scope of the proposed dynamic study includes these items:

    a. Recycle System Assessment assesses the recycle system capacity with respect to the compressor wheel map, confirms the size/capacity (adequacy) of the system for the steady state operating range, and includes modeling of the compressor, piping system, and valve characteristics.

    b. Start-up and normal shutdown protocol assesses the start-up and normal shutdown protocol to evaluate the valve shutdown sequence, timing, rates, and the driver ramp down (turbine, motor, engine, etc.).

c. Slow Transient Analysis provides independent checking of the compressor surge control protocol during slow transient events such as inadvertent closure of suction and/or discharge valves (e.g. accidental shutdown).

d. Fast Transient Analysis, e.g. ESD, fast stop, or power failure) evaluates the entire system and the effectiveness of recycle system in severe dynamic conditions.

e. Evaluation of the piping system and provision of recommendations to avoid vibration due to FIV, FIT and AIV.

f. CENTRAN Transient Analysis simulation software to be used for Surge Control Analysis.

The deliverables include:

- Recommended changes to the control logic, recycle strategy, and other parameters
- A report defining surge control characteristics during upset conditions and across the operating window

3. Foundation or structural dynamics/vibration

Analysis and provision of recommendations to avoid resonance from reciprocating and rotating loads. This includes a Frequency Avoidance and Forced Response Analysis with the following factors:

a. Inclusion of all excitation loads such as pulsations and unbalanced forces throughout the compressor piping system.

b. Incorporation of all machinery on platforms including reciprocating compressors, centrifugal compressors, gensets, and pumps.

c. Integration of the pulsation and mechanical models (as per 1a and b, above) into the dynamic structural model to ensure accurate excitation forces and boundary conditions.

d. Use of ANSYS software for the Forced Response Analysis.

e. Consideration of worst case vibration interaction between machines.

f. Use of Wood's DataMiner software for specialized data reduction techniques to assess individual machines (operating conditions, locations, frequencies) and across multiple units.

4. **Piping vibration and integrity (avoiding piping induced fatigue failures)**

    a. FIV, FIT, and AIV design review for centrifugal compressors and associated piping system.

    b. Small bore piping/connections design review for all facility piping.

    c. Piping Vibration and Integrity Assessment as per EI Guideline (2008 AVIFF).

    d. Pipe Stress Analysis (thermal piping flexibility analysis) for vibratory loads. This is for applicable piping systems including dynamic/vibration issues as well as thermal design requirements. This includes modifications to the proposed piping layout, piping restraints, and support designs.

    e. Transient Vibration Analysis for Gas Systems as per EI Guideline 2008.

    f. Water Hammer Analysis for liquid systems.

Commissioning and operations

1. **Piping Vibration Inspection**

    - Main Piping Assessment
    - SBC and piping
    - Inspection to be conducted using include portable and multi-channel data acquisition (>100 channels) systems. Advanced testing includes relative vibration, FEA, stress measurements, etc.
    - Inspection includes visual assessment of pipe support and the restrain system
    - Testing to include transient conditions (where required)

2. **Reciprocating machines**

    - Pulsation and vibration baseline on compressor, driver, skid, vessels, and cooler
    - Includes verification of pulsation amplitudes, mechanical natural frequency testing on cylinders, vessels, and pulsation control devices

3. **Foundation**

    Baseline vibration measurements compared to guideline.

Vendor Qualifications

Wood Machinery Analysis is approved as a qualified vibration engineering firm. Other firms must be approved by the owner prior to project bidding.

Potential vendors must demonstrate they have the following corporate in-house capabilities (not through contractors) and submit documentation to verify compliance to each of these requirements:

1. Have global engineering staff in multiple countries (e.g., Canada, USA, Malaysia, and China).
2. Vibration design staff to include over 50 fully trained engineering experts with several years of experience in these vibration studies. Principal Engineers and Senior Engineers to lead advanced vibration analysis including:
    a. Dynamic Structural Analysis.
    b. Pulsation and Mechanical Machinery Analysis.
    c. Piping Vibration and Stress Analysis.
    d. Small bore piping/connection design.
    e. Transient and Surge Dynamic Simulation Studies.
    f. Torsional and lateral vibration.
    g. Structural and foundation dynamics.
3. FIV, AIV, FIT, Shell mode, ODS, and Performance Analysis.
4. Own and have more than 10 years of experience in operating the following simulation software:
    a. MAPAK, time domain acoustical, and mechanical software.
    b. Torsan, field verified torsional analysis software.
    c. CENTRAN, transient analysis simulation software.
    d. ANSYS, finite element software.
    e. CAESAR II.
    f. DataMiner post-processing software for dynamic studies.

5. Own and have 10 years of proven experience in field testing, troubleshooting, and inspections:
    a. RecipTrap for compressor analysis.
    b. Zonic hardware and software data acquisition system with over 100 channels of transducers.
    c. Data Physics Quattro for pulsation and mechanical analysis field testing.
    d. MHealth rotating performance monitoring and assessment software.
    e. ME Scope for Modal Analysis.
6. Field troubleshooting and inspection engineers:
    a. Over 10 dedicated field analysts (employees, not contractors).
    b. Audited Health and Safety Executive Program that is recognized and approved by global petroleum operators.
    c. Staff trained in Pulsation Analysis, Small Bore Piping Assessments, Modal Analysis, Torsional Analysis.
    d. Performance Analysis and Machinery Condition Assessment engineering experience.
    e. Capabilities for reciprocating compressors and pumps, centrifugal compressors and pumps, blowers, transient piping, structural vibration.