BETA
MACHINERY ANALYSIS

Design Requirements for Reciprocating Compressors

High reliability is achieved when the vibration related risks are properly addressed during the design phase. But not all compressor applications contain the same risk. For example, small compressors may have less forces and mechanical problems while higher risks are faced with:

- Larger units (over 500 HP or 375 KW) because they generate higher pulsations and shaking forces
- Compressors operating across a wide speed range
- Requiring many different operating conditions
- H2S, acid gas, and other types of gases
- More complicated piping systems, more stages, offshore applications, multiple units at a station, or other application factors

The following chart provides the suggested scope of vibration engineering. Based on the application risk level, the different activities and options are identified and briefly summarized.
To determine the application risk, please refer to [BETA's risk rating chart](). For application assistance, please do not hesitate in [contacting Beta's support staff.]()

Vibration Design Requirements – By Application Risk

	APPLICATION RISK			
Vibration Study Component	**Very Low**	**Low**	**Medium**	**High**
1. Torsional Vibration Analysis (TVA)	A TVA is required for new driver/compressor configuration, change in operating conditions, etc.			
2. Acoustic Induced Vibration (AIV) Analysis	Bottle Sizing only	Pulsation Analysis (acoustic study of compressor piping system)		
3. Mechanical Vibration Analysis	n/a	Mechanical Review	MNF Analysis (frequency avoidance)	MNF + Forced Response Analysis
4. Pipe Stress Analysis (Thermal Flexibility)	Strongly recommended (required) when coolers mounted off-skid			
5. Skid Design and Analysis	n/a	n/a Option: Lifting; and/or Transportation/Environmental Loading Analysis	Skid Review	Skid Dynamic Analysis;

Options:	
6. Small Bore Connection (SBC) Assessment	Evaluation of SBC design to assess stress and provide recommendations for improvement. Includes shop testing and recommended field baseline audit.
7. Foundation Design Analysis or; **8. Structural Vibration Analysis**	Evaluation of foundation design recommended for medium to large units mounted on piles or gravel, and for critical applications. Structural Dynamic Analysis is strongly recommended for offshore facilities (Platforms, FPSO).
9. Station Piping Pulsations **a. Off-skid Piping; and/or** **b.Multi-unit Analysis**	a. Off-Skid (Station Piping). To assess pulsations in coolers and scrubbers located away from compressor, or to assess pulsations in headers and plant piping system. b. Multi-Unit Analysis. Evaluate pulsations in header/plant piping when multiple compressors are connected together in series or parallel.
10. Transient Vibration Analysis: **a. Fuel Gas Booster and/or** **b. ESD/ Blowdown**	a. Fuel Gas Booster: Ensure pulsation limits from booster compressor to gas turbine meet the owners and OEM specifications. b. Transient surge analysis of ESD (blowdown analysis) to ensure acceptable stress to piping system during ESD events.

Standard Vibration Studies

The API 618 Standard and GMRC High Speed Guideline (discussed below) require these vibration design studies. These studies are highly integrated and share common input files and assumptions. To avoid errors, conflicting recommendations, and delays, one consultant should perform all the studies.

1. **Torsional Vibration Analysis (TVA).** Evaluates torsional dynamic stress of the unit drive train for all anticipated machine operating conditions, including upset or transient conditions. Provides recommendations to avoid resonance and ensure torsional stress is below guideline, based on mass-elastic model, torque effort curves, forced response, etc.
2. **Acoustic Induced Vibration (AIV) Analysis**. Performs an acoustic simulation of the piping system and recommends a pulsation control solution. Evaluates the entire operating map and piping system. Provides solution based on an optimize design that considers pulsation forces, bottle mechanical natural frequency, pressure drop (and impact on power consumption), and capital costs. Standard study includes 20 operating conditions, including pressures and load steps. Option to add additional operating conditions.
3. **Mechanical Analysis**. Recommended for medium and large installations. Includes mechanical review of piping system and frequency avoidance analysis. Assesses pulsation forces and gas forces across relevant harmonics to avoid resonance conditions, using a finite element model. For higher risk applications, forced response analysis is recommended to calculate vibration and stress amplitudes. Deliverables includes recommendations to avoid resonance, or to manage resonance.
4. **Pipe Stress Analysis** (Thermal Flexibility Study). Evaluates thermal loads between compressor and coolers, other process piping, and cooler/vessel nozzle loads. Appropriate boundary conditions used to avoid simplistic assumptions such as “anchor” or “rigid.” Can include pipe support design.
5. **Skid Design and Analysis**. Skid review ensures adequate stiffness and load path at key locations. Can include lifting, transportation, and environmental loading. Dynamic analysis includes forced response applying compressor and driver loads, gas forces, crosshead forces and significant pulsation forces

Optional Vibration Studies

Good design practices often require additional engineering, as outlined below.

6. **Small Bore Connections Assessment**. Highly recommended to avoid gas releases and vibration induced failures. The failure of SBC is the most common piping failure on a compressor system. Often these connections are resonant, so small vibrations on the main pipe can cause these components to vibrate excessively and fail. See recommended articles below for more information. A shop or field test is also recommended to measure actual MNFs and vibrations.

7. **Foundation Design and Dynamic Analysis** for large compressors. It is common practice to evaluate the foundation and ensure it will not be resonant with the compressor forces.
8. **Structural Dynamic Analysis** (FPSO, Platforms). Highly recommended for offshore applications as these facilities do not have the solid mass (e.g., concrete block) to properly support the compressor skid, so decks and beams on platforms and FPSOs are often resonant with the compressor(s) and engine(s). This study provides recommendations to avoid resonance. See BETA's website for more on structural vibration.
9. **Plant Piping Pulsations**:
   a. Off-skid or Station Piping. BETA will assess pulsations in piping away from the compressor package (if information is available). This added level of analysis is valuable when coolers and/or scrubbers are located away from the compressor package, or when pulsations need to analyzed in the headers and plant piping system.
   b. Station Analysis (interaction between compressors). When multiple reciprocating compressors or a combination of reciprocating and centrifugal compressors are used at a compressor station, care is needed to avoid pulsation interaction in the suction or discharge headers. This study evaluates the pulsation interaction and provides design recommendations to minimize pulsation amplitudes.
10. **Transient Analysis**:
   a. Fuel Gas Booster Analysis (Receiver Sizing Transients). Gas turbines require a tight tolerance on its feed gas. Pressure pulsations that are too high will affect the turbine operations. BETA has developed a unique approach to evaluate these pressure pulsations at the inlet to the turbine, and provide recommendations to ensure limits are achieved.
   b. Blowdown Analysis. With high pressure application such as gas storage with multiple compressors, high 'fluid hammer' forces and vibration will be generated when blow down valves are opened for ESD. The blow down analysis will help to determine the sequences and time interval of opening of blow down valves, payout of blow down piping and supports.

Industry Standards (API, GMRC):

Three well-established standards for completing the above vibration studies are:

- **GMRC High Speed Guideline** (2013). This Standard provides extensive information for designing a reliable high speed compressor system (750 RPM and higher). While targeted for gas pipeline and storage applications, it can be used for any high speed application. Chapters 6, 7, and 13, and appendices 3, 6, and 7 are directly related to vibration control.
- **API 618 5th Edition**, Chapter 7. This Standard applies to low speed compressor systems (<750 RPM). It originated in the refinery/petrochemical industry where large compressors are typically used. The Standard defines the vibration requirements for compressors and related piping, but does not address foundation, skid, small bore connections, or other areas. A new edition is expected to be released in 2014.
- **API 688**. Originally developed as a Recommended Practice (RP-688), this will soon be released as an API Standard for reciprocating compressors and pumps and will contain detailed information about vibration and pulsation related issues.

Comments on API 618 Definitions:

API 618 Design Approach includes both Pulsation Analysis and Mechanical Analysis. In earlier editions, API used "M" nomenclature to describe components of a Design Approach. This nomenclature is still widely used by some engineers. For example:

- Design Approach 2 (DA2): M2 and M4: includes pulsation study with mechanical review
- Design Approach 3 (DA3): M2-M5: basic pulsation and mechanical analysis (resonance avoidance). M6 and M7 studies are advanced mechanical analysis (forced response) on compressor manifold and off-skid piping.