New API Standard 618, 5th Edition (released Dec 2007) –
Changes to Pulsation, Vibration, Torsional, Skid, and Piping System Flexibility Studies

Background

The new API Standard 618 (5th Edition) affects how packagers and end users specify and purchase pulsation and vibration studies for reciprocating compressors. Application Note1 has two parts: This Application Note, 1a, outlines the requirements of API 618 5th Edition ("the Standard"); Application Note 1b shows the implications of the Standard for packagers and end users.

Description of Application Note 1a

This Application Note provides an overview of the key topics in API 618 relating to **Pulsation** and **Vibration** control (mechanical design). The Standard also addresses engineering analysis of **Torsional Vibration, Dynamic Skid Design, Piping System Flexibility (Thermal), and Foundation Design**. These sections of the Standard are generally applied for all compressors (including high speed compressors).

There are a number of important technical and commercial implications affecting how the pulsation and vibration studies are quoted and implemented on reciprocating systems. See **Application Note 1b** for a summary of these implications.

Beta Machinery Analysis (Beta) provides seminars on this topic and other aspects of pulsation/vibration designs.

Summary of API Standard 618 and Key Changes in the 5th Edition

API Standard 618 is the recognized specification for users and manufacturers of reciprocating compressors. The Standard can be purchased on online at http://www.api.org or http://www.IHS.com.

API Standard 618 defines pulsation and vibration design requirements for reciprocating compressors. This Standard is used throughout the industry and includes high speed machines.

The 4th Edition was published in 1995. During the past several years, the industry has identified many enhancements to this Standard.

The purpose of API 618 is to establish the **minimum requirements**. However, extra requirements are needed to optimize the compressor design to lower total life cycle costs and maximize performance and efficiency. Compressor Design Optimization is discussed in **Application Note 1b**.

To ensure a global standard, API 618 5th Edition has been reformatted to be harmonized with the ISO requirements. We understand the next revision will be jointly issued as a merged ISO and API document.

The following points summarize key changes incorporated in the 5th Edition.

Mechanical Analysis:

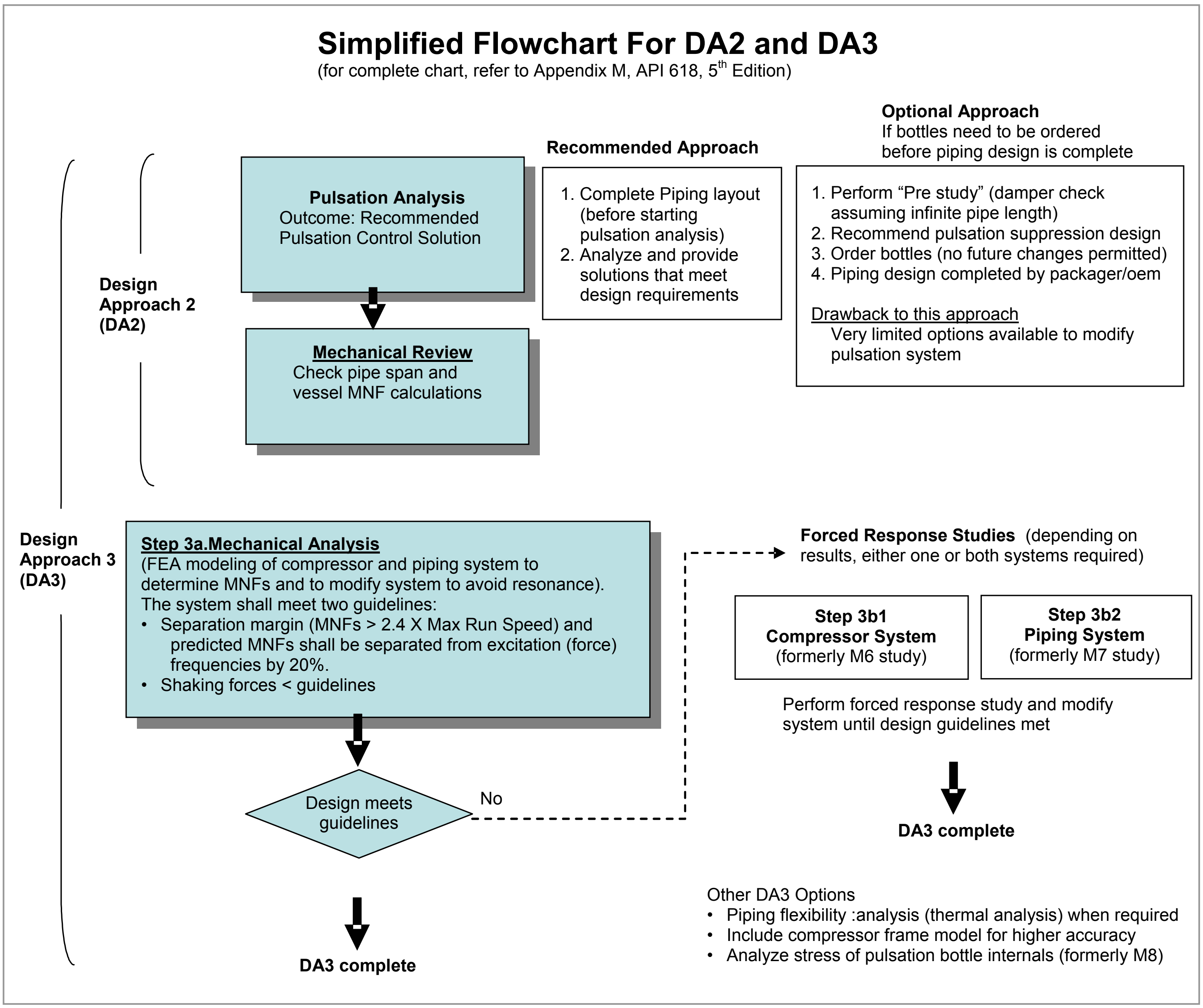
- The forced response studies (formerly known as M6 and M7 studies) are no longer required on all Design Approach 3 projects. These studies are only required if the pulsation and Mechanical Natural Frequency (MNF) design do not meet the required guidelines. In addition, this new Edition provides more specific instructions on how these studies should be performed to ensure accurate results.
- The former M8 study (stress analysis of the bottle internals) is optional and is to be done only if specified by the end user.

- The margin of separation between the MNF and force excitation frequency is ±20%. In addition the minimum MNF must be over 2.4 times maximum run speed.
- Vibration and stress guidelines have been updated.

Pulsation Analysis:

- For cases where the piping design is not available, the pulsation supplier can perform a “pre study” or damper check to calculate bottle sizes. There are consequences to this approach (see below).
- Unbalanced force guidelines for piping and vessels are defined
- Line side pulsation guideline has been updated to account for the specific speed of sound of the gas (allows for high pulsations in low density gas and lower pulsations in high density gas).

The end user and packagers are encouraged to exceed these standards to improve efficiency and reduce total life cycle costs. We refer to this as optimized design practices. (see Application Note 1b, section 3).



Pulsation and Mechanical Analysis (section 7.9)

- Has 3 different design approaches (consistent with 4th Edition).
- No longer uses "M study" terminology to designate the separate study components (e.g., M2 for pulsation study, M3 for performance analysis).
- General Comments:
  - Pulsation analysis must consider full range of conditions including different gas analysis, all planned operating conditions and load steps (section 7.9.2).
  - If multiple units are connected together through a common piping system, then a multi-unit analysis is required to ensure the cumulative pulsation effects are addressed (complies with section 7.9.3).
- The new edition includes the following application chart (see below). The recommended study scope is based on the compressor discharge pressure and rated power per cylinder.

Selection Chart: For Pulsation/Vibration Study Scope

(note: DA1 = Design Approach 1, etc.)

Absolute Discharge Pressure	**Rated Power per Cylinder**		
	Kw/cyl < 55 (HP/cyl < 75)	55 < Kw/cyl < 220 (75 < HP/cyl < 300)	220 < Kw/cyl (300 < HP/Cyl)
P < 35 bar (P < 500 psi)	DA1	DA2	DA2
35 bar < P< 70 bar (500 psi < P < 1000 psi)	DA2	DA2	DA3
70 bar < P < 200 bar (1000 psi < P < 3000 psi)	DA2	DA3	DA3
200 bar < P < 350 bar (3000 psi < P < 5000 psi)	DA3	DA3	DA3

A more detailed application selection chart is called the Risk Rating Chart (see www.BetaMachinery.com > Support). Application Note #2 also provides guidelines for which study scope is recommended.

- Allowable pressure drop criterion now acknowledges dynamic pressure drop as well as steady state pressure drop.
- **Design Approach 1 (DA1)**: basic bottle sizing using empirical calculation. This does not include pulsation study (consistent with 4th Edition).
- **Design Approach 2 (DA2)** (Step 2):
  Scope: includes pulsation control in conjunction with a mechanical review (basic vessel calculations and review pipe runs and anchoring system). Consistent with 4th Edition.
  - Pulsations analyzed with acoustic simulation including different approaches depending on the availability of the compressor pipe layout.
  - Does not include mechanical modeling to calculate mechanical resonances.

  Preferred approach: piping system is defined. The pulsation analysis will provide a more reliable, efficient and lowest overall pulsation control solution (compared with alternate approach discussed below).

  Alternate approach: piping system is not defined. Initial bottles sized based on damper check or "pre-study." A damper check is an acoustical simulation of the gas passages and bottles based on a line connection with infinite length.
  - Benefits: allows for pre-ordering vessels.
  - Disadvantages: May be difficult to optimize the system; pressure drop may be higher; bottles may need to be re-designed; and additional analysis needed at a later date to determine support requirements.

- **Design Approach 3 (DA3):** includes Step 2: Pulsation analysis (per DA2 above) plus:

  Step 3a. Accurate Modeling of Mechanical Natural Frequencies (MNF). Analyze compressor and piping system to avoid mechanical resonances at frequencies where significant shaking forces exist. Factors that influence accuracy are discussed below.

  - This step was formerly known as M5 study of compressor manifold.
  - The design shall meet two key parameters:

    1. Separation Margin between mechanical natural frequency and the shaking force frequency (also called excitation frequency).

    Minimum MNF of any element in the system > 2.4 maximum run speed AND predicted MNF shall be separated from significant excitation frequencies by ±20%

    2. Acoustic Shaking Forces shall not exceed the limits based upon the calculated effective static stiffness and the design vibration guideline. API 618 defines a method for estimating the effective stiffness of the piping and the bottle without conducting comprehensive mechanical modeling.

  If design guidelines for Steps 2 and 3a are met, API 618 Design Approach 3 is complete. If any of the guidelines are not met, Steps 3b(1) and/or 3b(2) will be required to meet Design Approach 3 requirements.

  Forced response analysis may be required (contingent on step 3a results)

  Step 3b(1). Compressor Mechanical Model Analysis

  This step applies to the pulsation suppression devices (bottles). If the separation margin or shaking force criteria in step 3a above cannot be met, a forced response analysis of the compressor mechanical model must be conducted. The analysis is to include the pulsation shaking forces and cylinder gas forces.

  - This analysis was called the M6 study in the API 618 4th Edition.
  - The design must meet the allowable cyclic stress criteria (per 7.9.4.2.5.2.5).

  Note: The cylinder gas forces (also called frame stretch or cylinder stretch forces) can cause excessive pulsation bottle vibrations even if the pulsation shaking forces meet the Standard. *API 618 5th Edition does not provide any guidelines for an acceptable cylinder gas force*. Based on Beta's experience, the Compressor Mechanical Model Analysis is required when:

  - HP/cylinder >750 or rod loads exceed 80% rated rod load.
  - Wide speed range operation is required (more than 25% of rated).
  - Compression ratio is below 1.7
  - Needed for a critical application.

  Step 3b(2). Piping System Analysis

  This step applies to the piping system. If the separation margin or shaking force criteria in step 3a, above, cannot be met, a forced response analysis of the piping system to pulsation shaking forces must be done.

  - This analysis was formerly called M7 study in the API 618 4th Edition.
  - The design must meet the allowable cyclic stress criteria (per 7.9.4.2.5.2.5) and vibration limits (per 7.9.4.2.5.2.4).
  - Piping system may include all piping included in the pulsation (acoustic) analysis but is generally limited to specific areas where the forces exceed the guideline, or the mechanical design criteria cannot be met.
  - Based on Beta's experience this study is seldom required for standard compressor packages.
  - There is a benefit to the packager or end-user for conducting this analysis in specific cases such as;
    - New installations where bottle material has been purchased.

- Existing installations where making pipe layout, or support changes, are difficult.
- Design optimization studies where analyses have competing requirements. A typical example, is the elevated piping around air coolers. The hot discharge piping requires a flexible design to minimize nozzle loads, but the mechanical design for minimum vibration requires a stiff design.

Torsional Vibration Analysis (TVA)

"The compressor vendor shall perform the necessary lateral and torsional studies to demonstrate the elimination of any lateral or torsional vibrations that may hinder the operation of the complete unit within the specified operating speed range in any specified loading step."

Typically, lateral critical studies are not required for reciprocating compressor applications. Lateral natural frequencies will be positioned well above significant torsional natural frequencies or any forcing frequencies generated by the compressor or driving equipment.

"The compressor vendor shall provide a torsional analysis of all machines furnished (except small belt units). *The study shall eliminate any harmful lateral or torsional vibrations for all specified speed ranges and loading steps*."

A stress analysis shall be performed if the torsional resonance falls close to the torsional natural frequency. The stress analysis is to ensure that the resonance won't be harmful for the compressor system.

- See section 6.7 (sub sections 6.7.1, 6.7.2, 6.7.4).
- The TVA report includes graphic display and data used in mass elastic system, graphic display of forces vs. speed (and frequency), torsional critical speed and deflections (mode shape diagram), and effects of recommendations to proposed changes.

Dynamic Skid Analysis

The dynamic skid study (including forced response analysis) is outlined in section 7.5.4.14, and is strongly recommended for packages mounted on offshore platforms, or modules mounted on steel columns.

Beta recommends that a dynamic skid analysis be conducted for

- new or unproven skid designs,
- 2 throw, high speed, variable speed compressors, and
- skids mounted on concrete foundations (and gravel pads) where the local soil conditions are suspect.

Although not part of API 618, a skid lifting study, transit study, and environmental loading analysis are often required. Beta recommends that the same party conduct all skid studies.

Implications for Foundation Design

While not addressed in this Standard, the assumption is that the end user has specified a foundation design including dynamic analysis of shaking forces and the interaction of loading on the gravel, pile, or concrete foundation. Dynamic analysis of reciprocating compressor foundations requires specialized knowledge, experience, and simulation tools. The party to conduct the foundation design must be carefully selected.

The accuracy of the dynamic skid analysis is strongly influenced by the design of the foundation for offshore installations or onshore pile installations. The dynamic skid analysis must include modeling and simulation of the foundation at the same time. Separate dynamic analysis of the skid and foundation cannot be done accurately.

Beta has the capabilities to perform dynamic analysis for offshore structures and foundation designs (reference article, *Dynamic Analysis of Reciprocating Compressors on FPSO Topside Modules, 2007*, www.BetaMachinery.com).

Piping Flexibility (Thermal) Analysis

Sections 7.9.4.2.3.6 and 7.9.4.2.5.2.5.2 refer to the piping system design including the effect of piping movements due to temperature changes as well as weight, pressure, and other factors. The thermal design often requires that flexibility be added to the system. This requirement is counter to the requirement for more support (increased stiffness) to meet the mechanical natural frequency design required. Beta recommends that the same party conducting the Design Approach 2 or 3 study, to control vibration, also conduct the piping flexibility study. The purpose of this is to minimize design iterations and result in an overall optimized design.
The Thermal Analysis (formerly M11 study) is optional.

Additional Resources

Our other Application Notes may be useful for end users and packagers (http://www.BetaMachinery.com > Support > Application Notes):

1b: Implications of the New API 618 (5th Edition) for Packagers, OEMs, and End Users
2: What API 618 Scope of Pulsation and Vibration Study is Required?
3: How to Avoid Scrubber Vibration and Resonance
4: Confusion With Mechanical Studies (Forced Response Studies)
5: Compressor Frame Model Increases Accuracy in Mechanical Studies
6: Vibration Issues on Compressors With a Wide Speed Range