Abstract

When performing a piping flexibility and dynamic analysis for reciprocating compressors systems, modeling techniques can be very critical. Higher fidelity models provide better predictions of the systems flexibility and dynamic behavior. The intent here is to briefly summarize the benefits of TTI's advanced modeling techniques for clamped piping systems by focusing on major key points. Guidance per ASME & API to support the following approach is also referenced throughout this paper.

Piping Analysis Model

A typical piping analysis model (Figure 1), piping and the support structures are included the same study model. Analysis models including the structural pipe support (i.e. beams, pier and piles) are critical to obtain accurate support stiffness and mass contribution. This method increases the ability to accurately predict a system's mechanical natural frequency and response**.** The process piping, compressor skid beams, off-skid support structures and pipe rack are incorporated in one single analysis model. De-coupling these components in the study can result in predictions that are inaccurate and may result in potential vibration failures.

*-Per API 688 – 3.2.7.4 "Pipe support structures (e.g. I-beams, A-frames, and pipe racks) often run overhead, with relatively low flexibility in the horizontal direction as a result. In addition, they add mass to the system. Neglecting the mass and flexibility of such structures can again lead to an over prediction of the systems natural frequency, easily on the order of 20% to 50%." "From **Table 3**, it can be seen that the system including the pipe rack is much more flexible than without the pipe rack."*

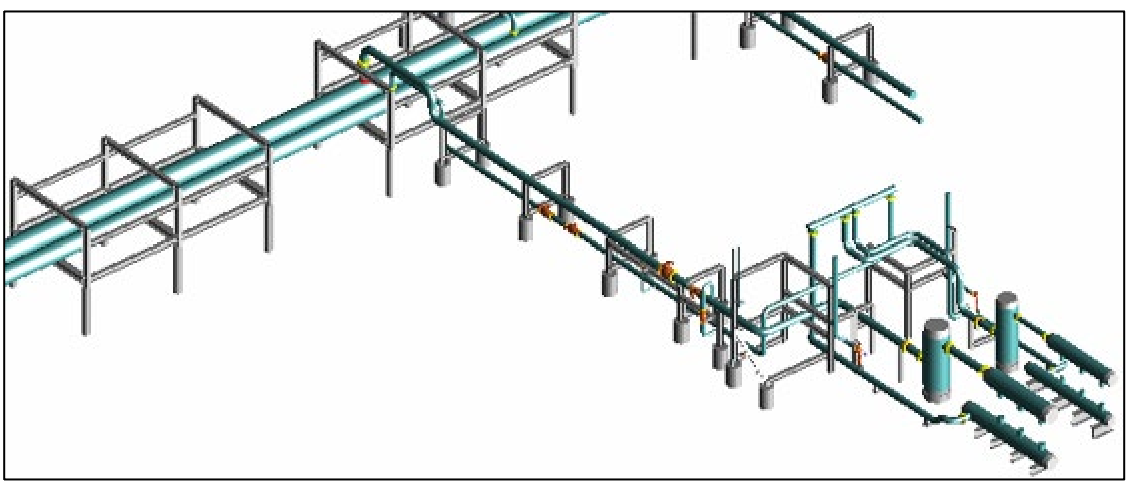


Figure 1

As shown in Figure 2, as thermal expansion occurs, the piping causes member displacement (Md), then thermal displacement overcomes the clamp load (Cd), which then equals the total pipe displacement (Pd).

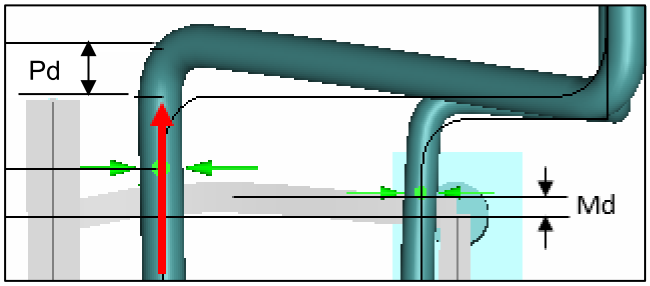


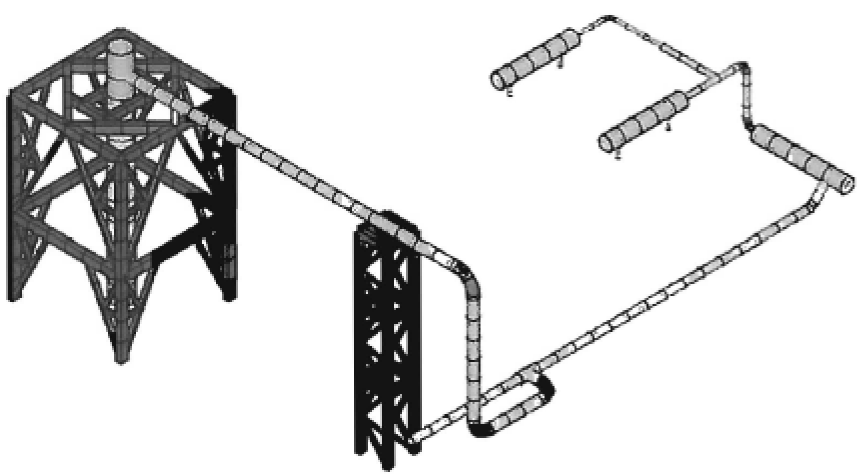
Figure 2

(Md) Member displacement = 0.0985”
+ (Cd) Clamp displacement = 0.2013”

(Pd) Pipe displacement (total) = 0.2998”

Table 3—Effect of Pipe Support Structures on Mechanical Natural Frequencies

Mode Shape Number	Frequency (Hz) Without Racks	Frequency (Hz) Racks Included
1	19.9	12.8
2	25.1	18.6
3	26.3	19.1
4	28.2	20.5
5	28.7	24.2



Clamp Preload Assumptions

The sole purpose of the clamp is to obtain a dynamically fixed support. It is a key factor to ensure preloads from the clamp are applied in the model. The clamp preload is used in our models to capture this piping behavior. This approach generates accurate stress and displacement results with accuracy that is reflective of field results and internal testing. The clamp pre-load is fundamentally calculated from the following:

- 2-bolt clamp for 1 ½ - 6” NPS
- 4-bolt clamp for 8” NPS and above
- ASTM A449 / SAE Grade 5 bolt, 85 ksi proofload (1/4’ -1”)
- Clampload to be approximately 75% of proofload
- Bolt diameter governed by pipe size
- 0.3 friction coefficient for steel to steel
- 0.1 friction coefficient for Teflon liners

-Per API 618 - 7.9.4.2.3.6 Note 2 - “To accurately predict and avoid piping resonances, the supports and clamps must dynamically restrain in the piping. Piping restraints are only considered to be dynamically restraining when they have either enough mass or stiffness to enforce a vibration node at the restraint. This requirement is difficult to achieve with overhead piping and/or the use of simple supports, hangers, and guides.”

During simulated piping thermal growth, the clamp has the tendency to pivot over and dig into the top of pipe causing the pipe to not slip **(Figure 3).** This issue needed to be addressed as it can cause major damage to the pipe or clamp. To prevent this our 8” lines and up were modified/modeled with a 4-bolt clamp design to prevent the clamp from this rotation.

Figure 3

Flexibility & Dynamic Analysis

A Flexibility and Dynamic Analysis are conducted per ASME B31 and API 618 respectively. A Flexibility (stress) Analysis is performed to prevent thermal expansion or contraction from causing fatigue failures, leakage and or distortion in piping or components.

A Dynamic Analysis is performed to ensure resonances in piping are not present and/or safely removed from excitation frequencies to cause failures. Utilizing simple supports such as shoes, guides, U-bolts or hangers are not "dynamically" fixed supports which restrain the piping to the support structure, therefore should not be used.

Table 1 illustrates what is included for a typical thermal and dynamic analysis.

Study	Support Stiffness	Support Mass	Friction	Clamp force
Static Analysis	Included	Included	Included	Included
Dynamic Analysis	Included	Included	Not Included	Included

Figure 4 shown below, illustrates a very simplified workflow for a typical piping study including a flexibility and dynamic analysis.

Figure 4

-Per GMRC Guideline 7.3.5, "Determining a final design that balances these competing design goals can be an iterative process. It is recommended that one party conduct the flexibility and mechanical analyses concurrently to optimize the design."

-Per ASME B31.3 Para 301.5.4 Vibration "Piping shall be designed, arranged, and supported so as to eliminate excessive and harmful effects of vibration that may arise from such sources as impact, pressure pulsation, turbulent flow vortices, resonance in compressors, and wind."

-Per API 688 - 3.2.7.9 - "Many pipe systems are optimized from the thermal point of view, but not from the dynamic point of view since guide and rest type supports are frequently used. These supports usually are not able to restrain the dynamic motions, and are therefore not advised for systems which are subjected to dynamic loads."