Colt Engineering - Edmonton

Stress Group

Notes on Piping Vibrations

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1. Introduction

Vibration occurs when a system is displaced from its stable equilibrium position. The system tends to return to its equilibrium position under the action of restoring forces (such as the elastic forces, as for a mass attached to a spring, or gravitational forces, as for pendulum).

Excessive piping vibration can cause real problems. Such as; threaded connections can loosen, Flanges can start leaking, Pipes can be knocked off their supports, and in extreme cases, a pipe fatigue failure can occur.

Also, most vibration causes increased stresses, energy losses, added wear, and increase bearing loads, induce fatigue, create passenger discomfort in vehicles, and absorb energy from the system.

Vibration is obviously too much if it causes a failure.

2. Vibration and Noise:

Noise and vibration are inter-related. Vibration deals (as does noise) with the oscillatory behavior of bodies. For this Oscillatory motion to exist, a body must possess inertia and elasticity.

Inertia permits an element within to transfer momentum to adjacent elements. Elasticity is the property that exerts a force on a displaced element, tending to return it to its equilibrium position. (Noise therefore relates to oscillatory motion in fluids while vibration relates to oscillatory motion in solids.)

3. Types of Vibrations:

Vibrating systems can be treated as linear or non – linear.

For a linear system, there is a direct relationship between cause and effect and the principle of superposition hold – i.e. if the force input doubles, the output response doubles.

The relationship between cause and effect is no longer proportional for a non-linear system.

3.1) Categories of the Vibrations of Linear Systems:

The vibrations of linear systems fall into three categories:

Free, forced and self-excited.

A- <u>Free vibrations</u> occur when a system vibrates in the absence of any externally applied forces (which is called a natural frequency).

B- <u>Forced vibrations</u>: occur at the excitation frequencies, and it is important to note these frequencies are arbitrary and therefore independent of the natural frequencies of the system. Rotating equipments usually is the source.

C- <u>Self - excitation vibrations</u>: is complicated phenomenon. The system vibrates under no periodic external forces and the vibration persists, due to internal energy, even in the presence of damping.

These excitation forces may be classified as being:

1) Harmonic, 2) periodic, 3) no-periodic (pulse or transient), or 4) stochastic (random)

The phenomenon of resonance is encountered when a natural frequency of the system coincides with one of the exciting frequencies.

4. Piping Vibrations:

There are two possible causes for a pipe to vibrate:

Mechanical or hydraulic.

<u>A mechanical induced vibration</u> is due to the mechanical vibration of a piece of equipment such as a pump or compressor which, in turn, causes the pipe to vibrate.

If the vibration frequency of the mechanical source is close to a mechanical natural frequency of the pipe, the pipe may amplify the vibration.

<u>A hydraulic induced</u> vibration is due to continuous pressure pulses that cause the pipe to vibrate.

The pressure pulses could be clearly periodical or more random and turbulent.

If the frequency of the pressure pulses (the hydraulic source frequency) is close to the acoustic frequency of the pipe cavity, the pipe will resonate and amplify the vibration.

To a casual observer, a most obvious effect of pulsations is that it forces piping and other plant systems into sustained vibrations and, under some conditions, the vibrations can cause fatigue failures at critical, high bending stress regions in the mechanical systems.

4.1) Common Piping Vibration Areas:

- Long Pipe Spans
- Piping Appurtenances
  (vents, drains, gages, Small bore connections. etc…)
- Large Masses (e.g., Valves and Components)
- Reciprocating Compressor Cylinders and Manifold Bottles

4. 2) Common Causes of Vibration:

- Excessive Pulsation (water hammer, control valves stations,…)
- Mechanical Natural Frequencies
- Inadequate Supports and/or Support Structure

5. Vibration's Prevention and Control:

There are three suggested approaches to control the piping vibrations:

- ➢ Supply mechanical restraints which will prevent movement of the pipe. For example: Hold down supports, guides, gussets, hydraulic snabbers, etc… (Mechanical-Piping stress)
- ➢ Eliminate or control the pulsations. (Process Engineering)
- ➢ Eliminate the coupling of pulsations as forces into the piping. Avoid un-necessary bends. (Mechanical – Piping Stress)

While each of these approaches is valuable, no one approach is optimum in all cases and any one by itself can prove excessively expensive.

The cost of mechanically restraining compressor piping or overhead plant piping, for example, causes the engineer to seek help from other control approaches.

A similar situation exists with pulsation control. If pulsation suppressors are designed to eliminate "all" pulsations (i.e., to a level that any piping system could be utilized) then it is found that pressure vessels of excessive size are required.

The concept of decoupling the pulsations from forcing the mechanical system into vibration will be involved in controlling the location of bends, constrictions and piping discontinuities relative to the pulsation standing waves.
It is difficult, for example, to excite an infinitely long, straight, constant diameter pipe into vibration from internal pulsations.

6. Recommendation:

- Provide adequate supports, guides, hold–down supports, hydraulic snubbers when it is required.
- All unnecessary bends should be eliminated since they provide a strong coupling point between pulsation excitation forces and the mechanical system.
- Gussets can be used in piping systems is that of small auxiliary piping connections such as vents, drains, pressure test connections, etc. However, care must be taken to ensure that the welding does not introduce high stress risers.
- Computer programs, such as CAESAR II ®, AutoPIPE and ANSYS can be used to calculate the natural frequencies and mode shapes of three-dimensional piping systems; however, their accuracy is highly dependent upon the assumptions of the end conditions.
- Also simplified tools or design procedures can be used, with experience, to provide effective designs which will not experience excessive vibrations or stresses.
- It is necessary to look for common symptoms of piping vibrations problems.

These include:

- Fatigue cracks in the piping,
- Leaks at flanges,

- Broken or loose pipe clamps or hanger,
- Cracked concrete piers,
- Rubbed weight supports (bright metal),
- Damaged pressure gages,
- Noise related to the pipe hitting its restraint, or high shell wall vibration.

7. Conclusion:

Finally, to minimize or eliminate piping vibration, it is the best to rely on experience during the design stage, follow good construction, practices during erection, and include pipe vibration monitoring as apart of the pre-operational or system startup test.

With certain flow conditions, piping systems will develop high levels of noise and vibration that can damage the pipes and related systems such as tube bundles, side cavities, and bluff or tapered bodies in flow streams. Pipe damage compromises plant safety, forces shutdowns, increases maintenance, and reduces efficiency and capacity.

Piping failures due to vibration have been a major cause of downtime and fires in industrial plants across the world. As a result, it is important to evaluate the vibration levels of piping systems to ensure the levels are acceptable. If vibration levels are considered excessive, modifications to the piping and/or its support structure may be required. Alternatively, the excitation mechanisms contributing to the vibration must be altered or eliminated. For modifications to be effective, it is necessary to understand the principles involved.

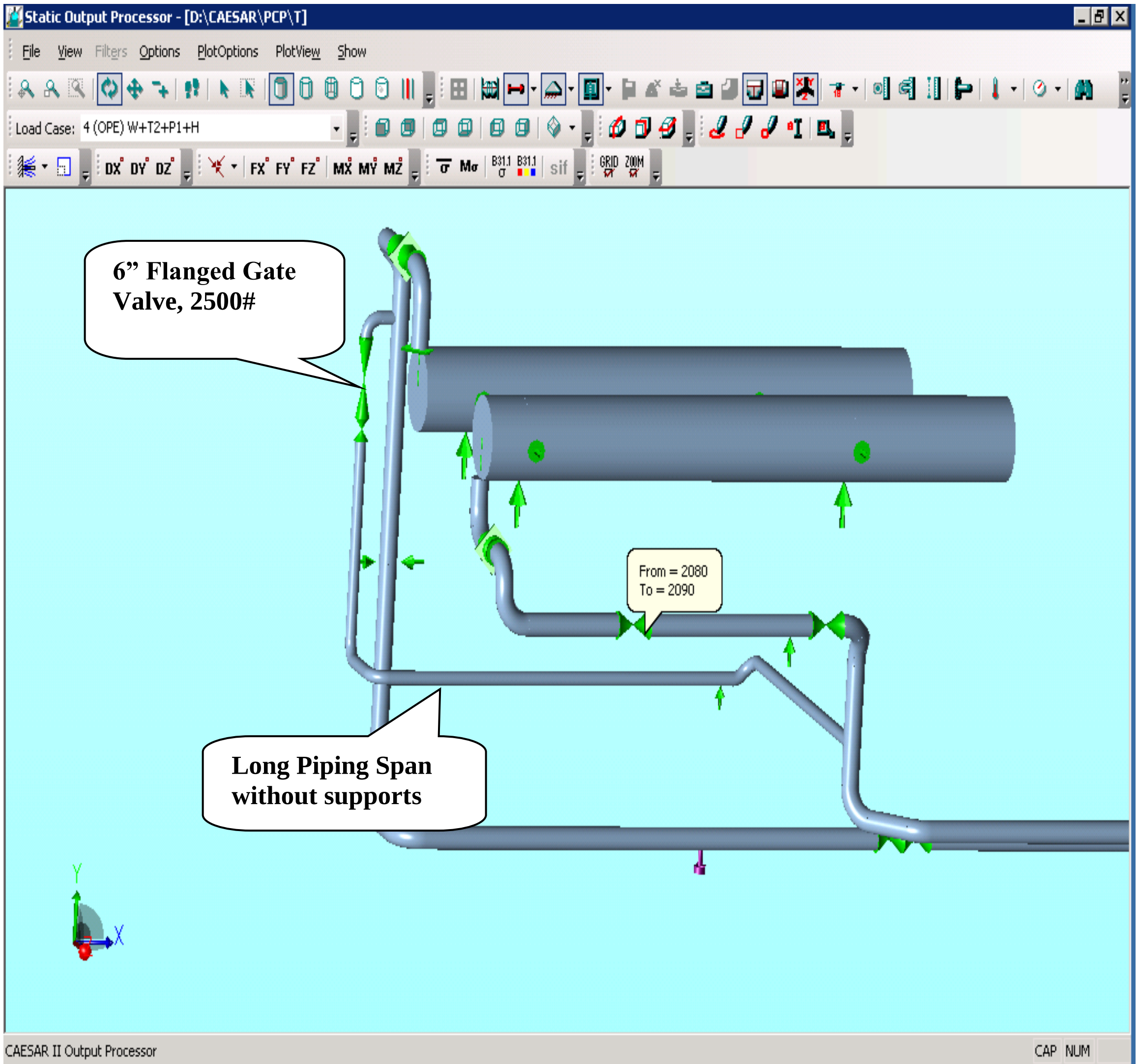
Don't Make the Situation Worse

A pipe will not vibrate if it is prevented from moving. However, this does not necessarily help the piping system design from the standpoint of its ability to absorb differential thermal expansion. Therefore, when addressing a vibration problem, the flexibility design of the piping system must also be considered. Restraints that are added to reduce vibration must not increase the pipe thermal expansion stresses or end-point reaction loads to unacceptable levels. It may sometimes be necessary to use hydraulic snubbers to stop vibration rather than fixed restraints. Such snubbers permit pipe thermal movement while still dampening vibration.

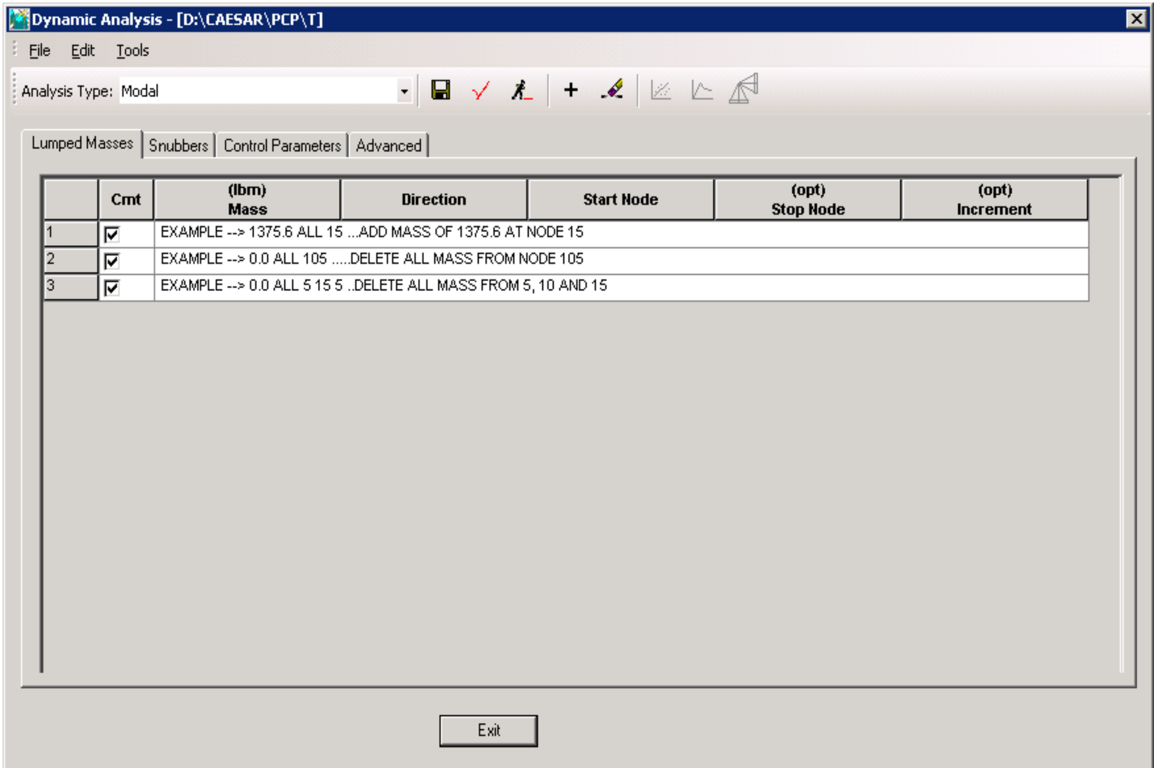
Technical vs. Psychological Vibration Problems

Piping vibration can result in two types of problems - technical or psychological. A technical vibration problem is one that has the potential to cause a failure (or has already caused one) and must be dealt with.

In many situations, a pipe can vibrate forever and never cause a failure. However, it might still be a problem, a psychological one, to the personnel in an operating unit who see it every day and are concerned about it. If it is easy and inexpensive to fix a psychological vibration problem, it is usually better to do that rather than try to convince operating personnel that everything is really fine with that pipe shaking.



Example of Piping Vibrations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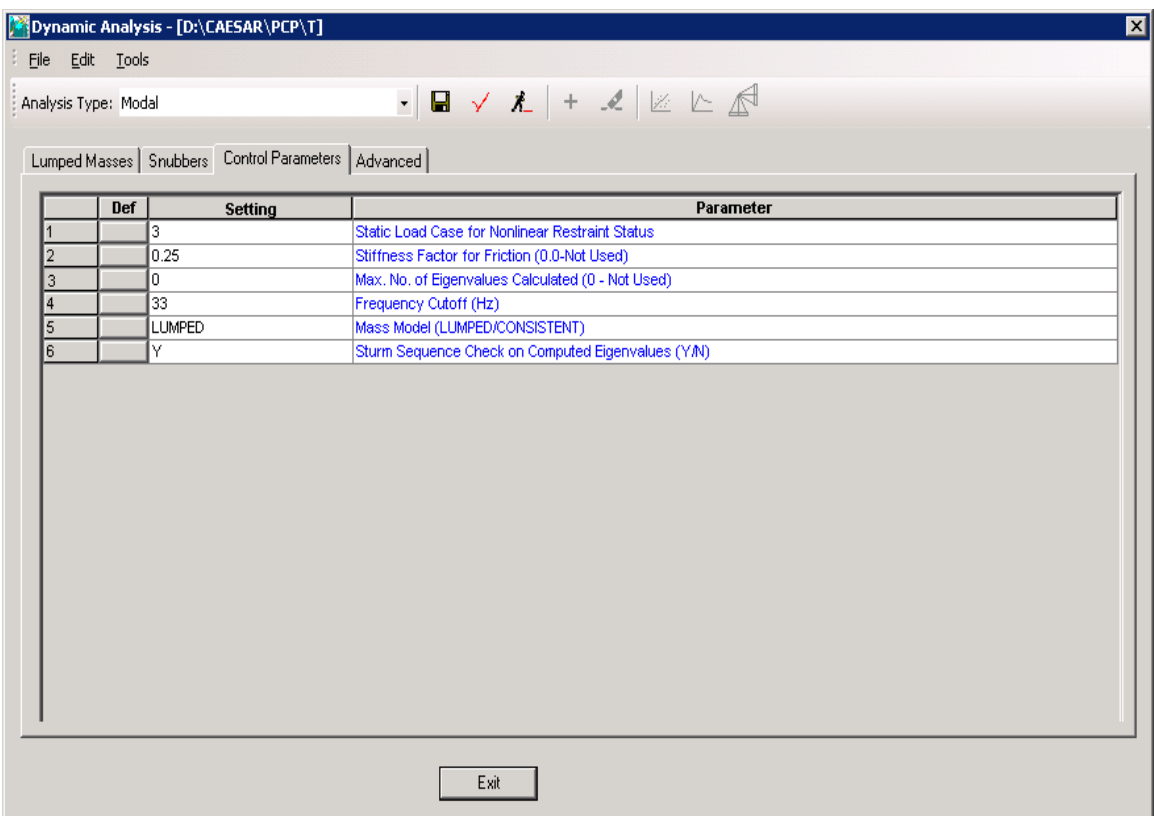
Lumped Masses
Snubbers
Control Parameters
Advanced
Cmt
(lbm) Mass
Direction
Start Node
(opt) Stop Node
(opt) Increment
1 EXAMPLE --> 1375.6 ALL 15 ...ADD MASS OF 1375.6 AT NODE 15
2 EXAMPLE --> 0.0 ALL 105 .....DELETE ALL MASS FROM NODE 105
3 EXAMPLE --> 0.0 ALL 5 15 5 ..DELETE ALL MASS FROM 5, 10 AND 15
Exit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File Edit Tools
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Lumped Masses
Snubbers
Control Parameters
Advanced
Def
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2 0.25 Stiffness Factor for Friction (0.0-Not Used)
3 0 Max. No. of Eigenvalues Calculated (0 - Not Used)
4 33 Frequency Cutoff (Hz)
5 LUMPED Mass Model (LUMPED/CONSISTENT)
6 Y Sturm Sequence Check on Computed Eigenvalues (Y/N)
Exit