Piping Design Considerations for Reciprocating vs Centrifugal Pumps

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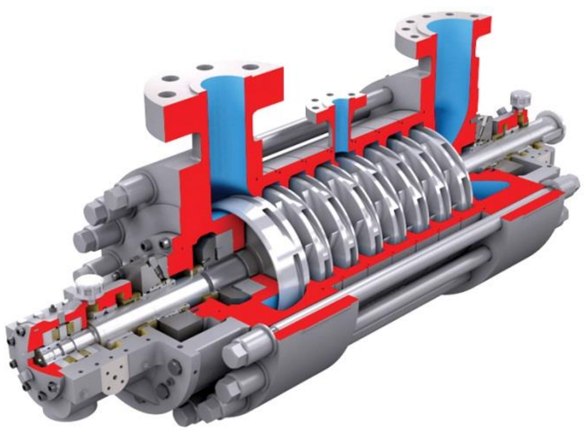
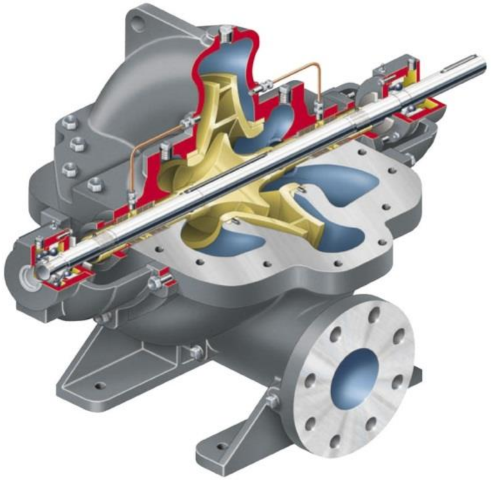
Jordan Grose, Manager, Vibration Integrity Group
BETA Machinery Analysis
A Wood Group Company





Presenters

Ramin Rahnama, PEng 	Ramin is a Project Engineer leading Design and Field teams in BETA's special needs projects, as well as developing tools for field vibration analyses. He received his Master's degree in Mechanical Engineering, specialized in Machine Dynamics, from the University of Calgary in 2010. Ramin has been with BETA for more than five years. He has extensive experience in machinery system vibration design by performing mechanical, pulsation, performance, and thermal stress analyses. He has also been leading vibration troubleshooting and maintenance projects for pump and compressor packages (on- and offshore) in many different countries. Besides his academic publications on vibration analysis in micro machining units, he co-authored "Improved Thermal Piping Analysis for Reciprocating Compressor Piping Systems" for the Gas Machinery Conference in 2012.
Jordan Grose, PEng 	Jordan leads BETA's vibration integrity department in addressing vibration, reliability, and integrity issues on rotating machinery piping systems, including pulsation, mechanical analysis, water hammer transient studies, small bore piping analysis, Energy Institute programs. He is a Mechanical Engineering graduate from the University of Calgary with a wide range of domestic and international design, field, and monitoring experience with compressors, pumps, and other production machinery. He has specialized skills in vibration, performance, and troubleshooting; and significant international experience in on- and offshore production facilities. Jordan has been with BETA Machinery Analysis for 12 years and was responsible for establishing BETA's Malaysia office. He has authored, co-authored, and presented several articles and technical papers on rotating machinery and piping topics.

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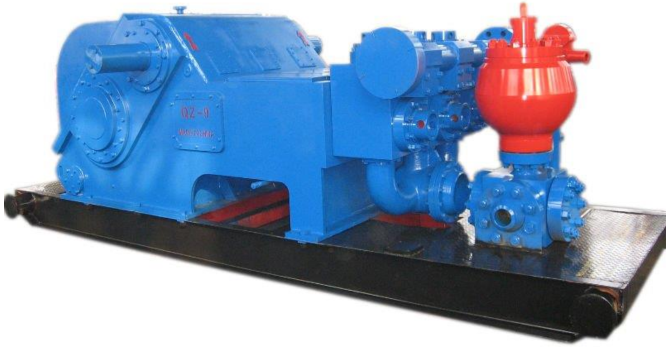
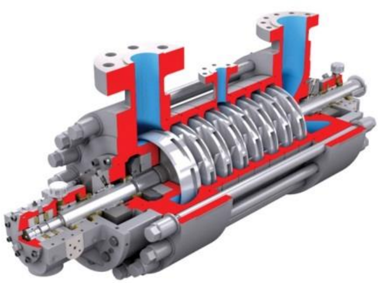
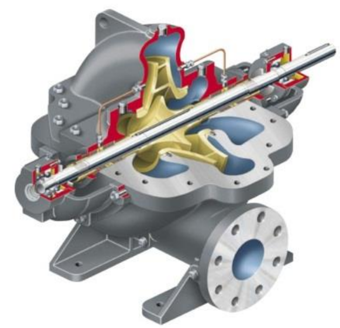


Key Points

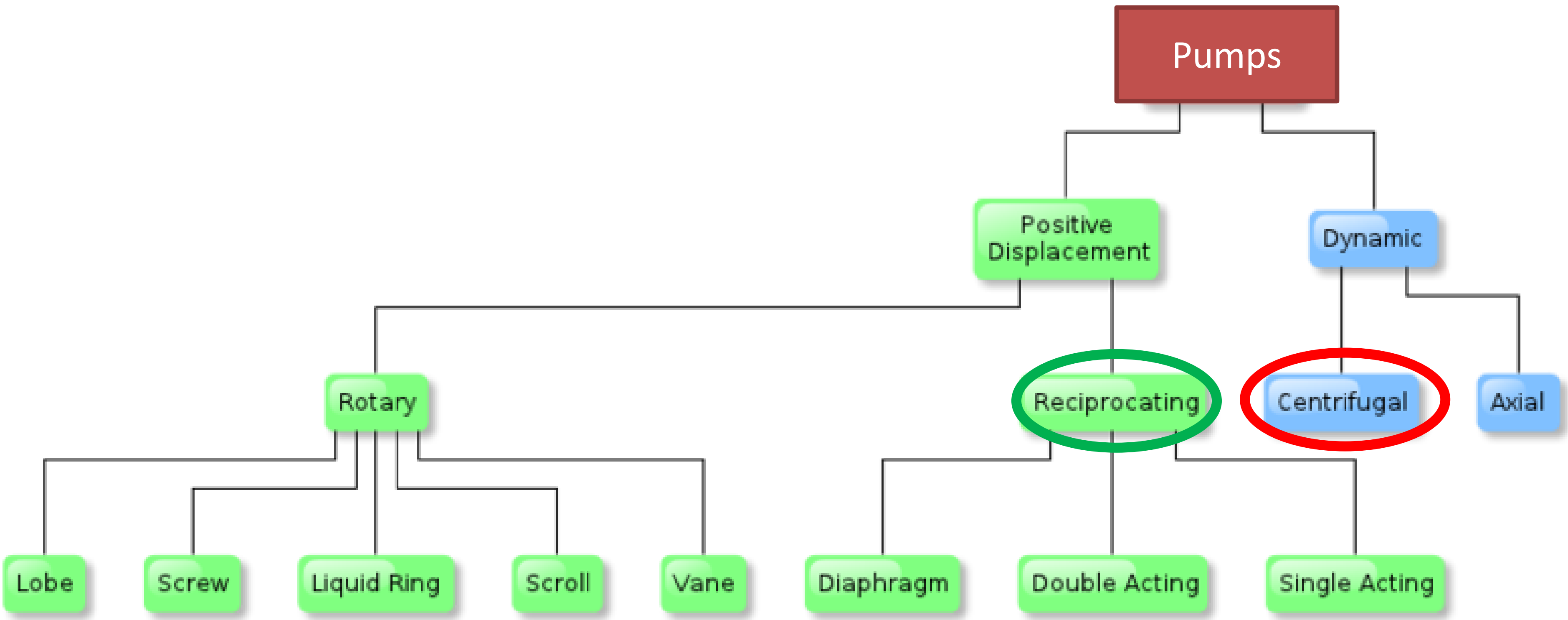
1. Differences exist between centrifugal & reciprocating pumps, and their behavior while interacting with the piping system
2. Reciprocating pumps have many additional piping design considerations, not needed for centrifugals
3. Pulsation must be considered in recip pump piping design
4. Mechanical piping supports must be considered
5. Small bore piping vibration must be considered in the design stage
6. Recip pumps can work well, if they are designed well!

Introduction





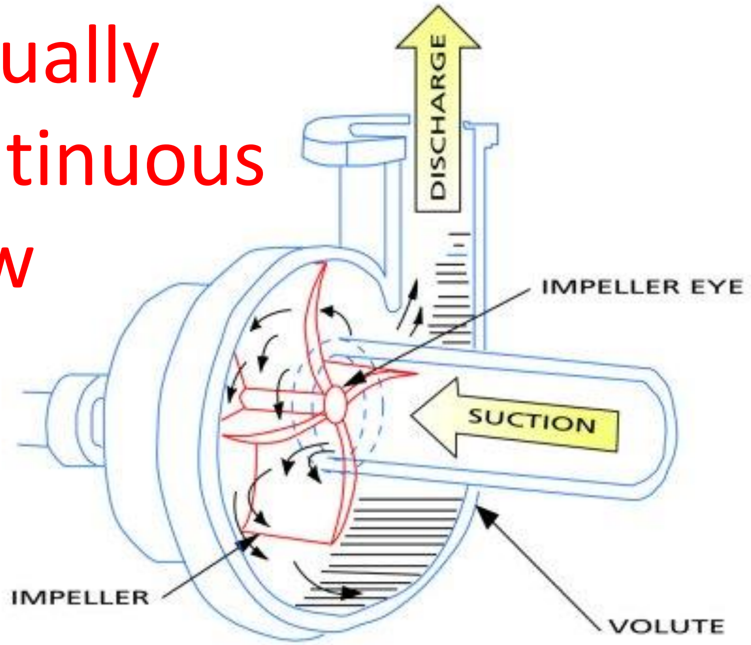
Pump Categories



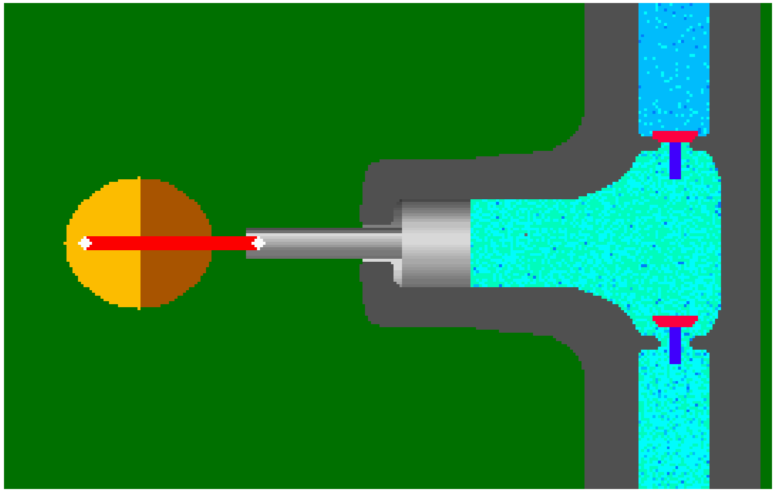
Working Principles

Centrifugal

Virtually Continuous Flow



Reciprocating



Intermittent Flow

Reciprocating Pumps - Applications

- High pressure (over 3000 psi)
- High viscosity
- Metering
- Non-Newtonian Fluids

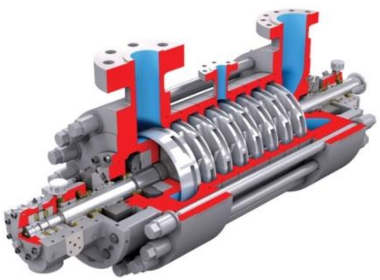
Characteristics

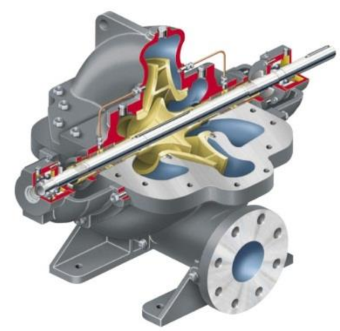
- Oil & gas
- Refineries
- Water treatments plants
- Cryogenic
- Food processing
- Fracking
- Pharmaceutical

Industries

Piping Design

Centrifugal vs. Reciprocating





Centrifugal Pump Piping Systems

LOADS

- Static
- Thermal
- Dynamics- Minimum

At steady state conditions, vibrations and pulsations are typically not severe

Standards

- API 686 RP
  - No Tee or elbow near suction nozzle
  - NPSH calculations
  - No High point
  - Straight pipe to avoid turbulences
- API 610
  - Nozzle forces and moments
  - Corrosion resistance
  - Pressure rating
  - Orifice size

No specification on piping supports or pulsations since dynamic loads are comparatively less!

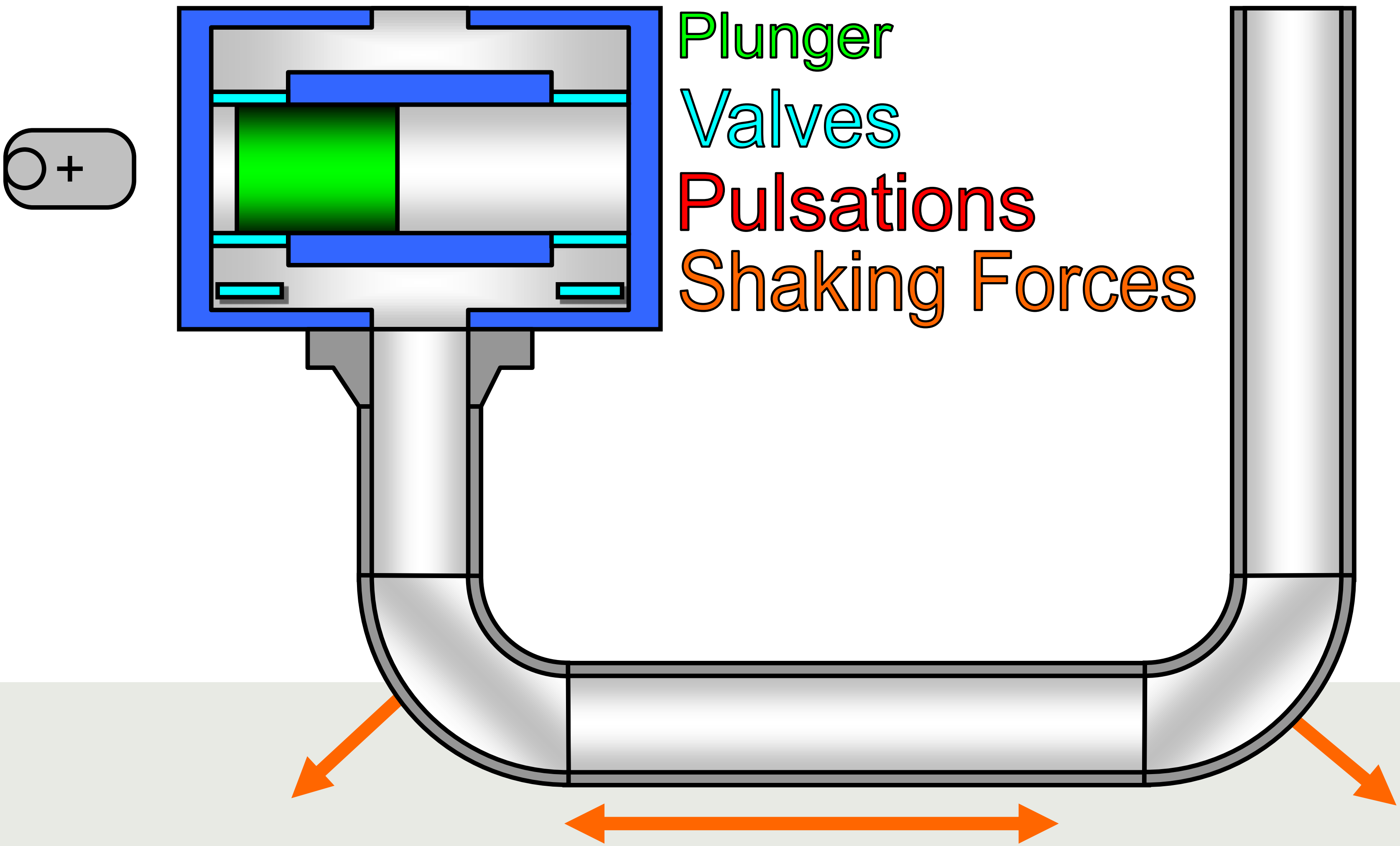
Reciprocating Pump Piping Systems

LOADS

- Static
- Thermal
- Dynamics - Large

→ Pulsations-induced forces up to 10,000 lbf

Pulsation in Reciprocating Pumps

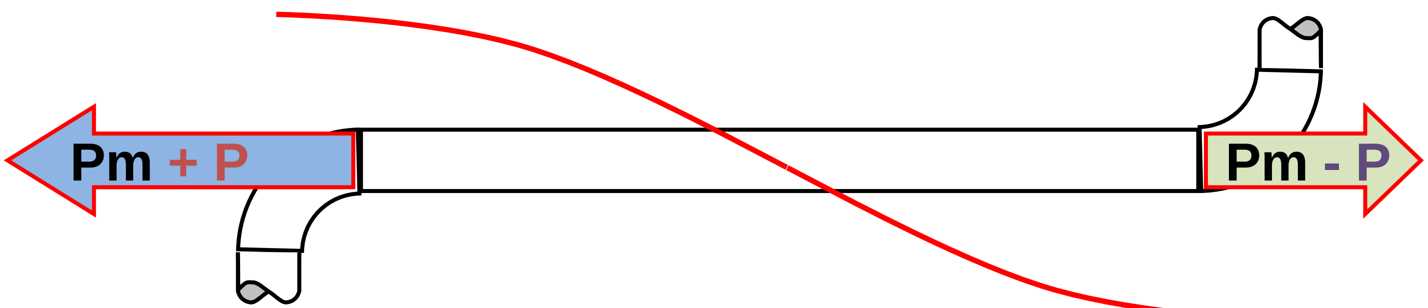


Pulsation-Induced Unbalanced Forces

Force (lbf) = Pressure (psi) * Pipe Area (in²)

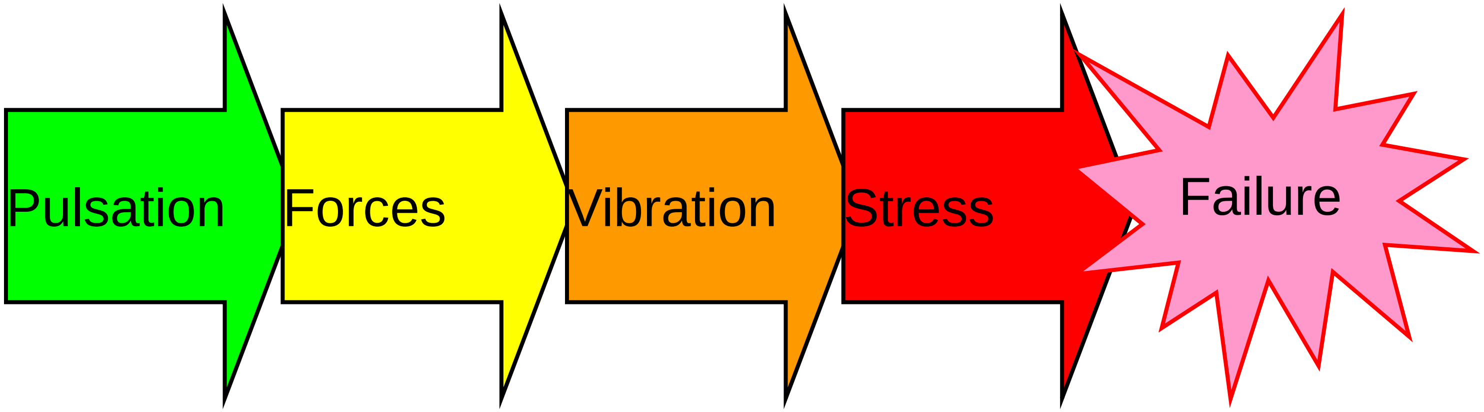
Pressure → Mean → Forces Cancel out

Pressure → Dynamic → Pulsation (time varying) → Acts on elbows & change in geometry



How Pulsations Cause Failures

- Pulsations in piping does not necessarily mean failures will happen…



- Forces, vibration, and stress caused by pulsations can be a problem

API 674/675 (for Reciprocating Pumps)

E.1.2 ACOUSTICAL ANALYSIS (ACOUSTICAL SIMULATION STUDY)

The accoustical analysis consists of using modeling techniques which account for the acoustical interaction between the pump and piping. The modeling method must account for the dynamic interaction of the flow through the valves and the resulting dynamic pressure variation in the pump passages and piping. Variations in specified operating conditions shall be analyzed by extending the applicable parameters of the analysis above an
conditions. This is normall
speeds above and below the
system must be modeled to
will have insignificant effe
under study (usually a larg
stream of the units to be stu
st lo

$$P_1 = \frac{100}{(ID \times f)^{1/2}}$$

E.1.3 MECHANICAL PIPING SYSTEM ANALYSIS

This study calculates the mechanical natural frequencies of the individual piping spans using published frequency factors, nomograms, computer simulation, and so forth to ensure that the piping span natural frequencies are detuned from significant pulsation excitation harmonics. From this analysis, the piping supports, clamp type, effective direction of restraint, and their locations are recommended. Thermal flexibility effects should be considered in the clamp designs and anchoring s

E.1.4 PUMP VALVE DYNAMIC RESPONSE STUDY

This study calculates dynamic response of the spring and sealing element, including interaction with the pump working barrel pressure and pump geometric parameters. It evaluates valve dynamic effects on pump dynamic flow characteristics, working barrel pressure, and valve impact characteristics.

Design tip: Pumps higher than 50 HP, should start thinking about a study

Design Approach 1 (DA1)

No pulsation study, good engineering judgment

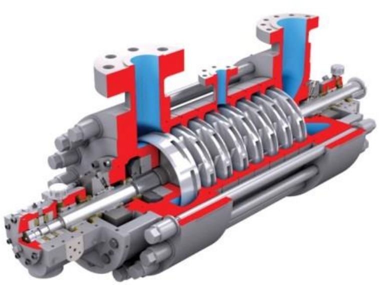
- Non-critical application (no significant impact if unit fails)
- Experience with similar units indicates the likelihood of successful operation.

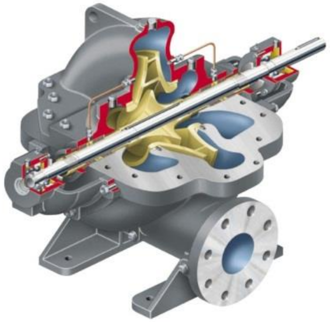
Design Approach 2 (DA2)

Digital pulsation study, valve dynamics, mechanical study

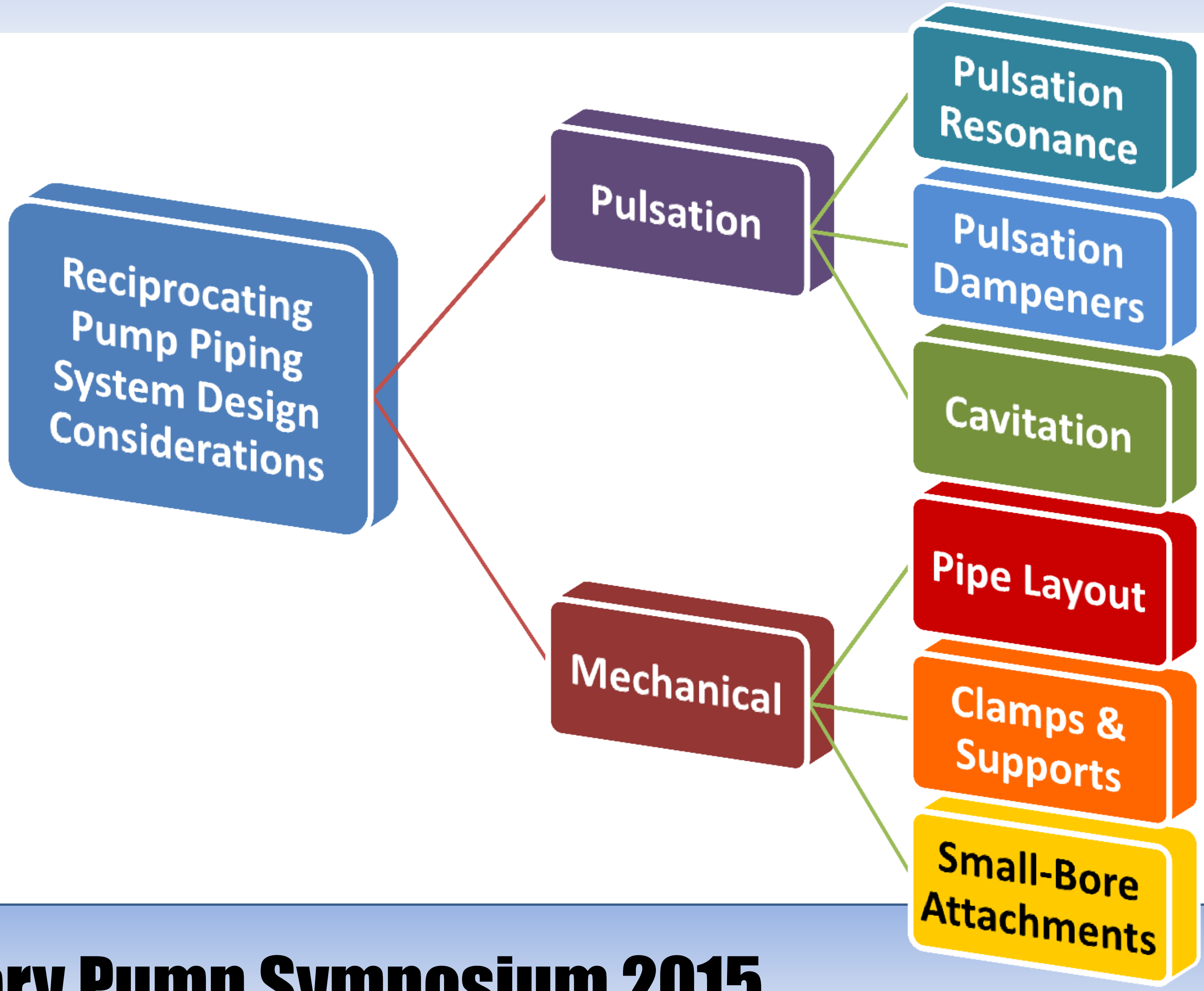
- Important application, or
- Variable speed applications, or
- Multiple units are online, or
- Variable operating conditions, or
- Multiple Fluids

Reciprocating Pump Piping System Design

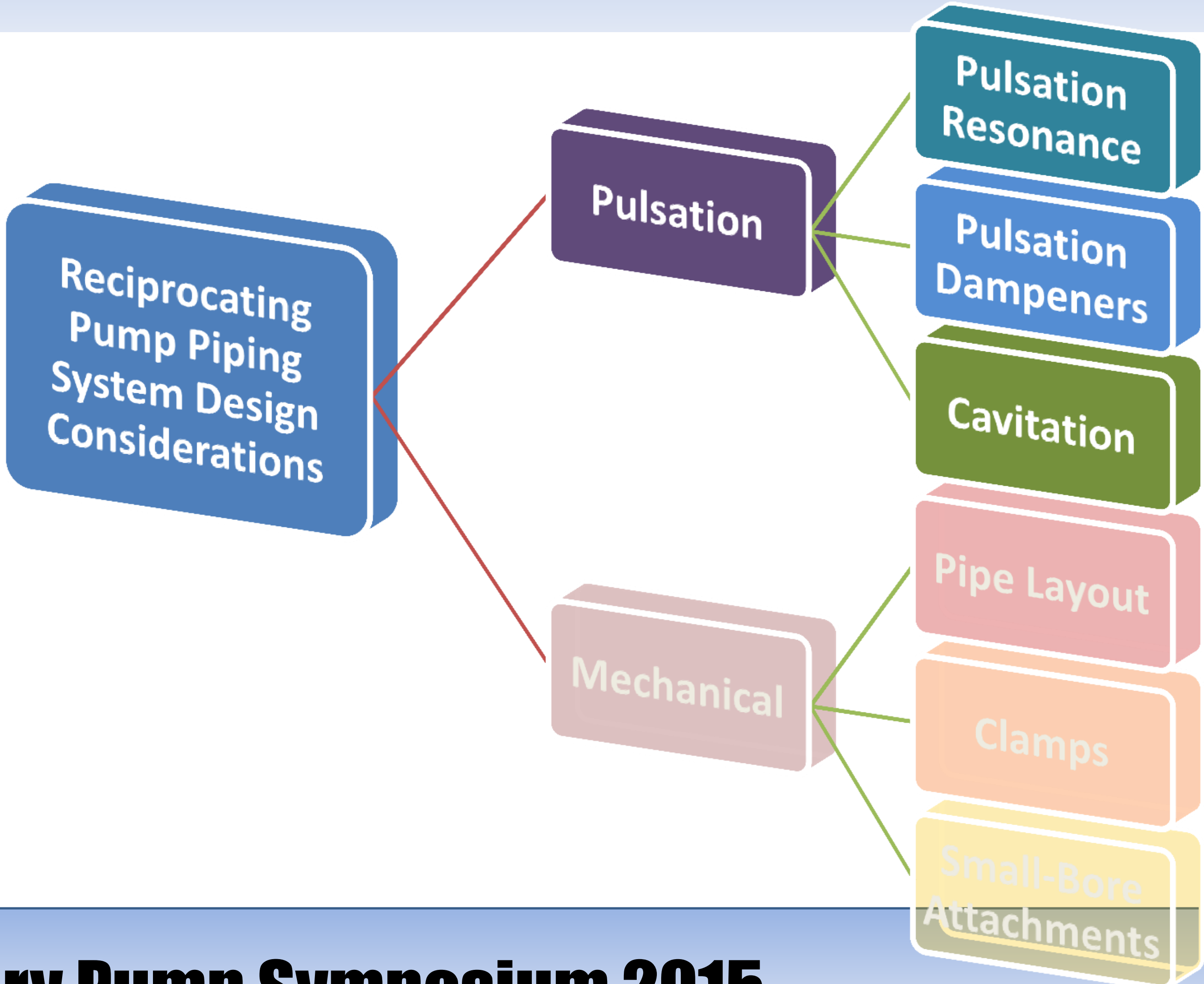




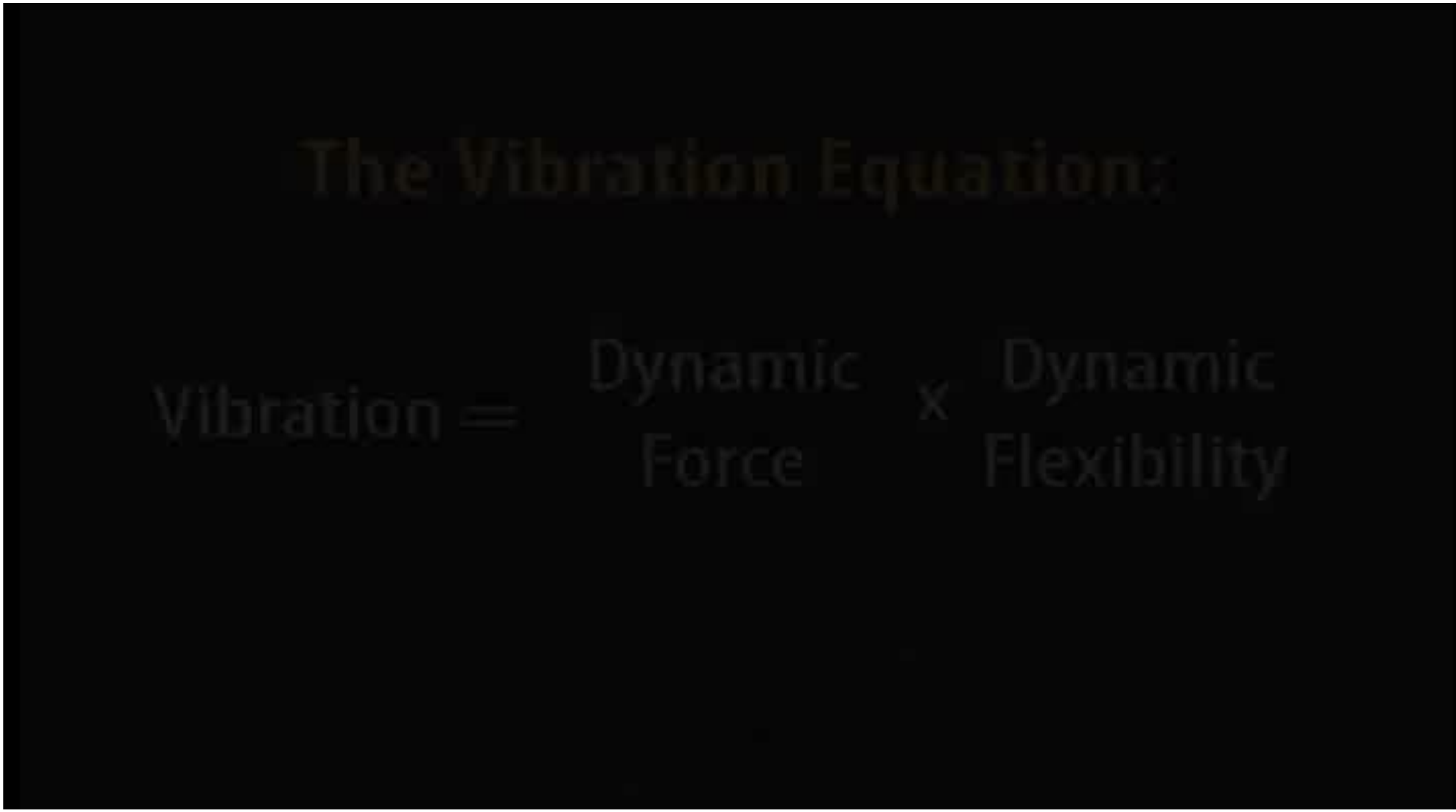
Design Considerations



Design Considerations

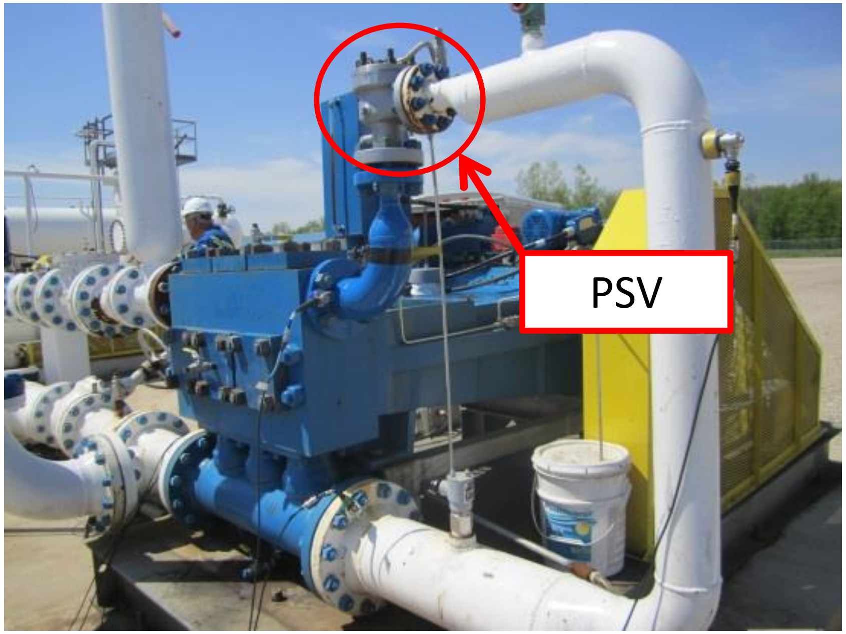


Pulsation Resonance : Video



Example: Pulsation Resonance

PROBLEM: PSVs popping at line pressures well under PSV set pressure
Cost $5,000 every pop to re-certify PSV



TROUBLESHOOTING

1. PSV OEM recommends new model $$$
2. Dampener OEM recommends new pulsation dampeners → $$$
3. **Pulsation Design Study ordered, showed pulsation resonance in PSV piping**
4. Root cause: Pulsation resonance in PSV line

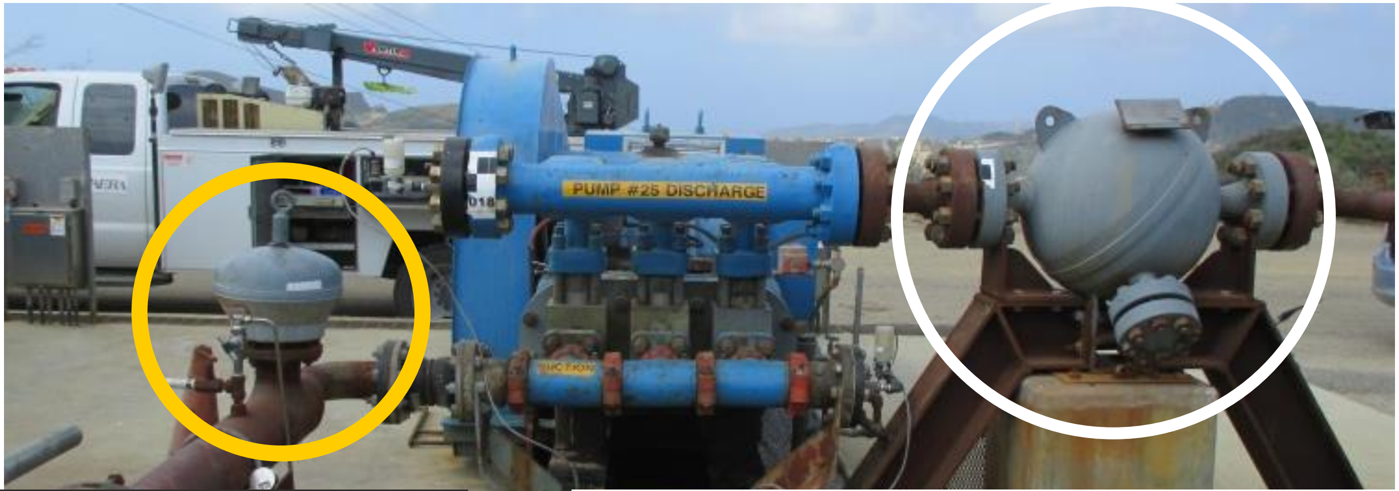
SOLUTION:
Move the location of PSV

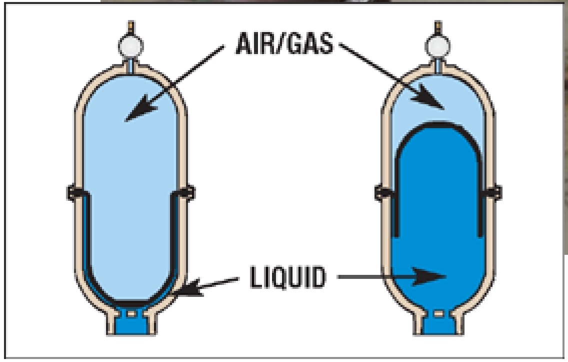
Design tip: Pulsation study can help with the troubleshooting process

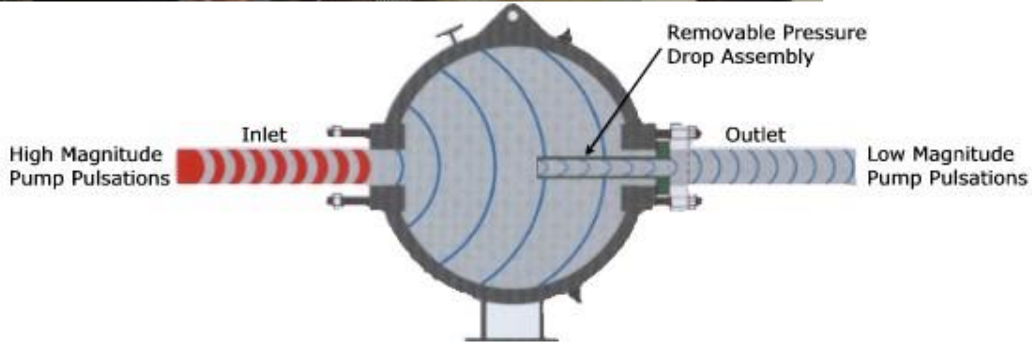
Pulsation Dampeners

Gas Charged
Active/Soft Element

Maintenance Free
Reactive/Hard Element







Pulsation Dampeners

	Gas Charged	Maintenance Free
Style	Appendage style	Mostly in-line (flow through)
Pros	• Compact • Off the shelf • Generally lower capital cost	• No maintenance • No spare parts • Very reliable, high frequency range
Cons	• Effective frequency range limited • Maintenance required • Bladder failures remove pulsation protection • Gas charging procedure not always easy	• Generally higher capital cost • Often custom design per application • Pulsation amplitude reductions can be limited

Pulsation Dampener Sizing

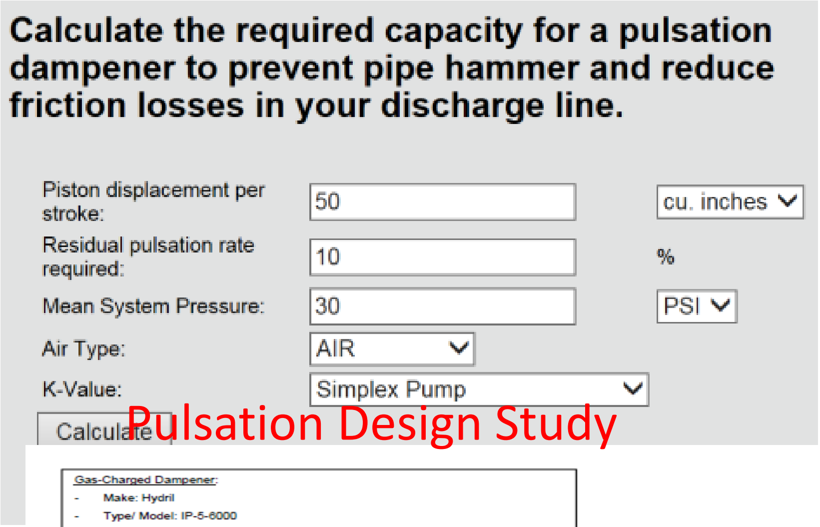
Traditional Approach

- Empirical calculations
- API 674 & OEMs have different empirical sizing methods
- Good first step for quoting, but…
- Do not account for acoustic resonances in piping system

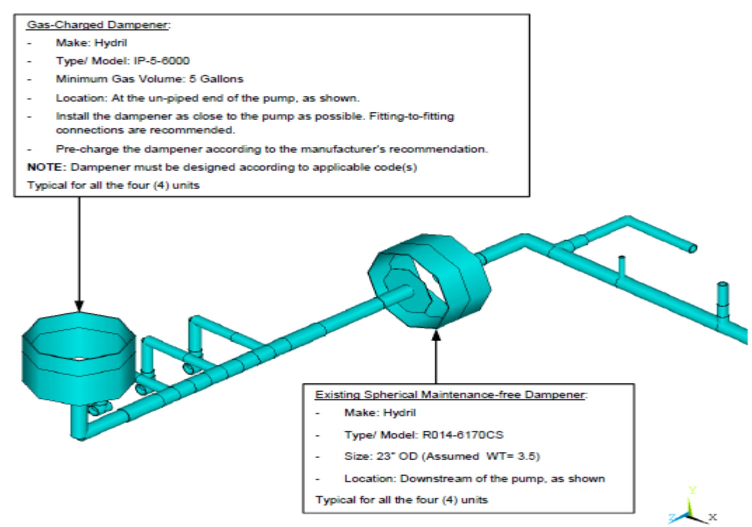
Advanced Approach

- Pulsation Design Study
- Benefits:
  - ✓ Complete range of operating conditions
  - ✓ All pump speeds
  - ✓ Multiple pump interaction
  - ✓ Optimized for:
    - All piping designs
    - Size and Location
    - Type (active vs reactive)
    - Number - sometimes none, one, or two

Empirical Sizing Methods



Pulsation Design Study



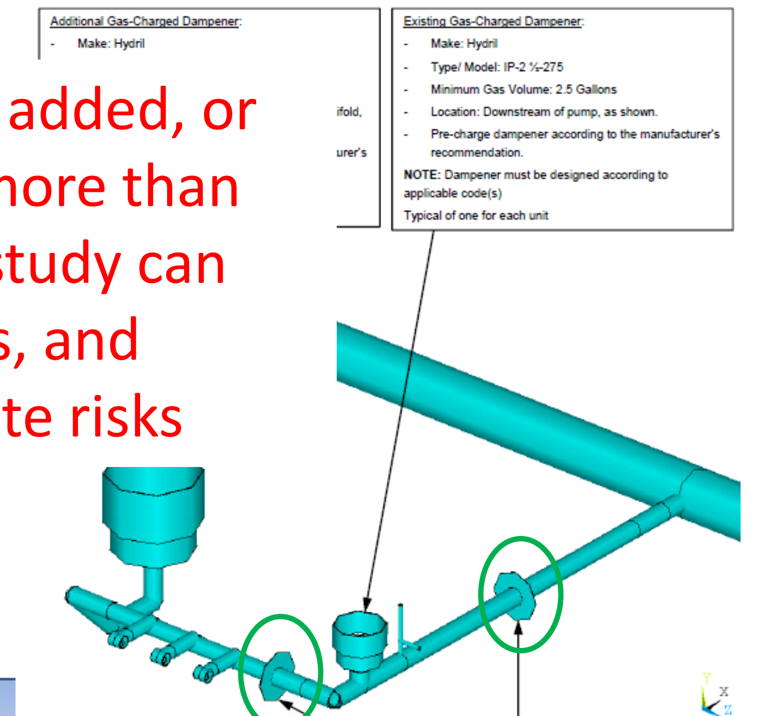
Example: Pulsation Dampener

PROBLEM: High vibration and pulsation after adding VFD drive (change in pump speed) & change in operating conditions

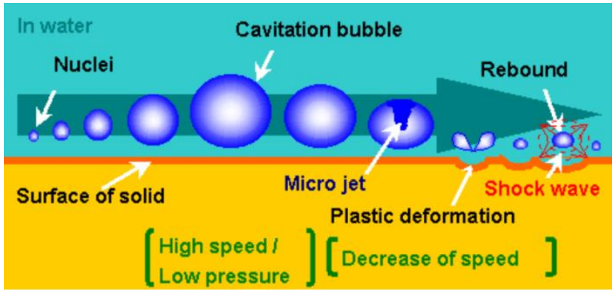
TROUBLESHOOTING: Pulsation Design Study highlighted inadequate pulsation control with new operating states. Solved the problem for new pumps speeds and operating conditions

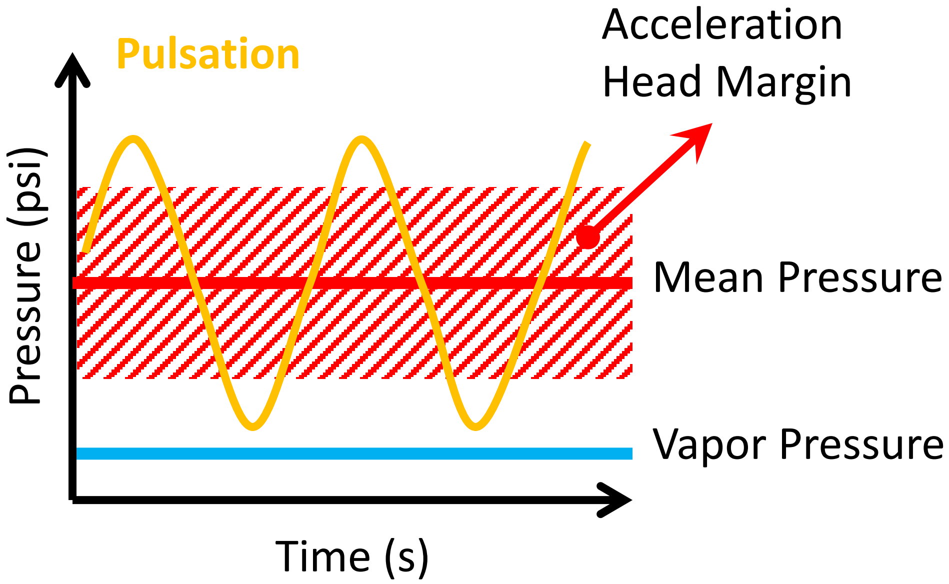
Design tip: If VFD added, or flows change by more than 10%, a pulsation study can predict the results, and proactively mitigate risks

SOLUTION: Additional Pulsation Controls



Cavitation





High pulsation increases the likelihood of cavitation. Acceleration head calcs do not account for pulsation resonances

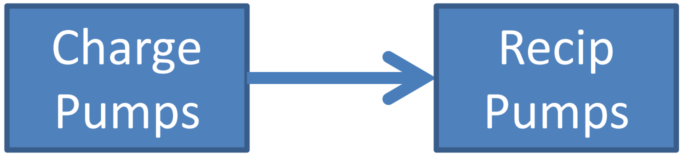
Example: Problems Caused by Cavitation

BACKGEOUND:

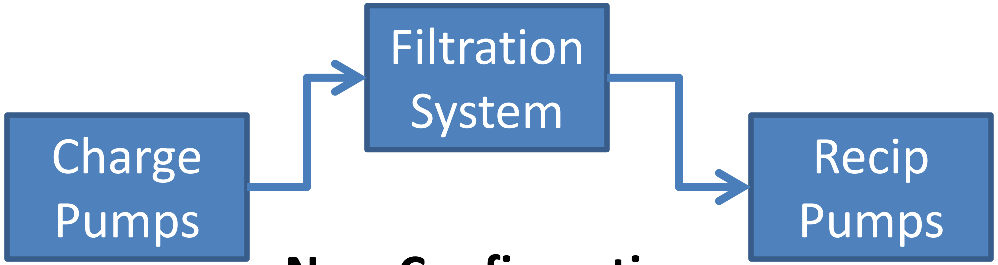
- Filtration system added
- Head loss calculations done
- No pulsation design study

PROBLEM:

- Cavitation on suction line



Original Configuration



New Configuration

Example: Problems Caused by Cavitation

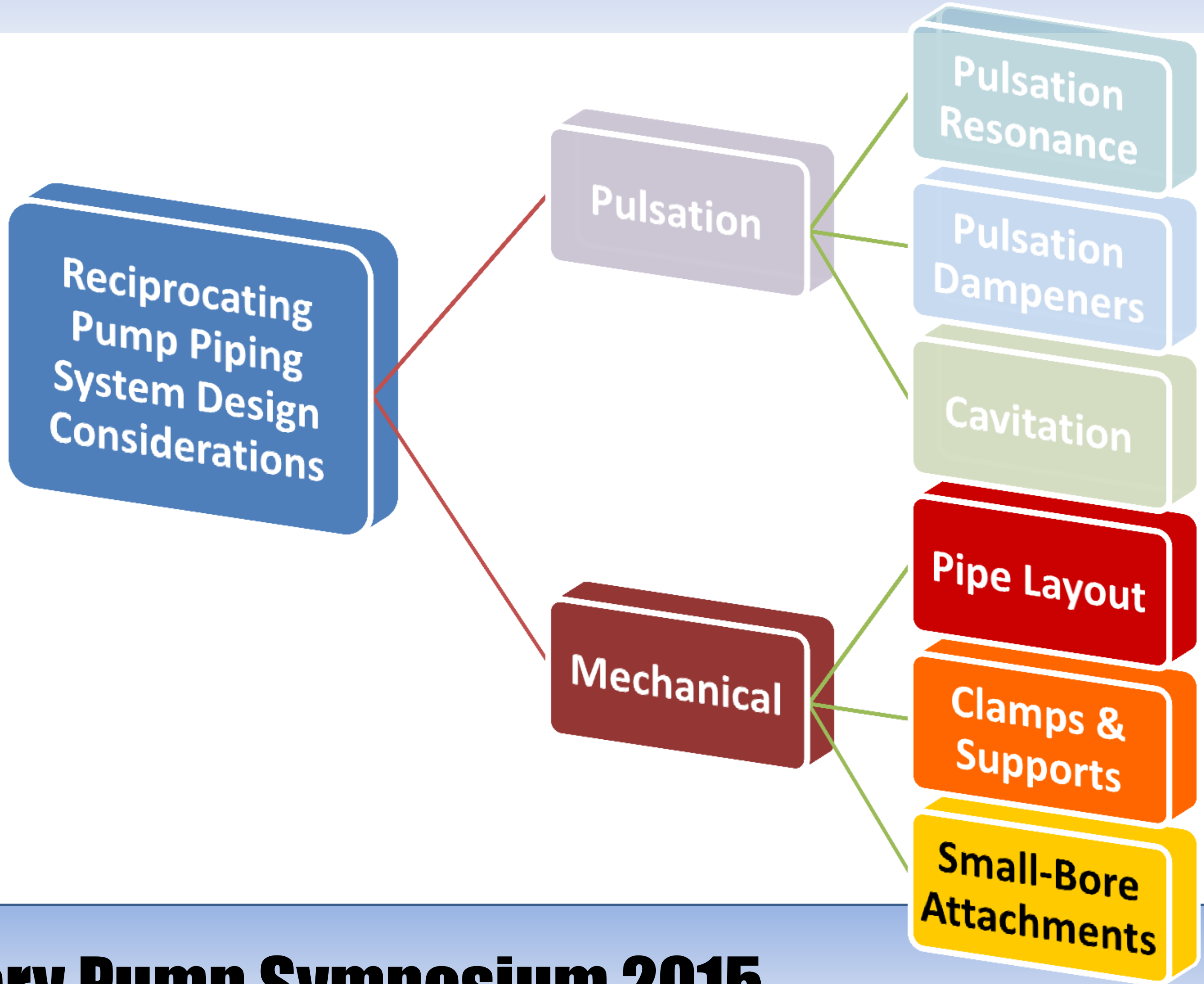
SOLUTION:

- Change in pipe layout
- Speed restriction
- Change in filtration process
- Up-size the charge pumps for more NPSH

Recently changed cylinder block

Design tip: Perform a pulsation design study before changing pipe layout or adding additional equipment, to avoid pulsation resonances!

Design Considerations

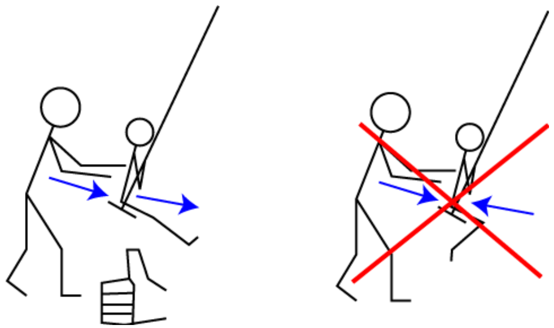


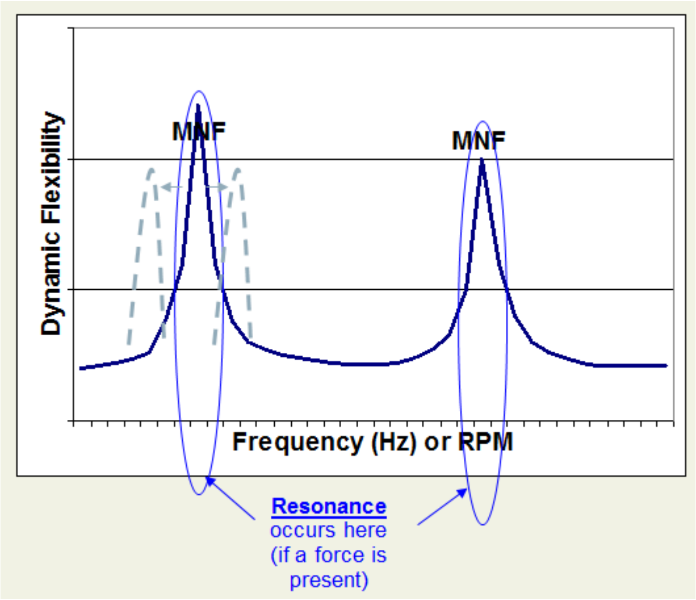
Mechanical Considerations

- Pulsation design **minimizes** pulsation-induced forces, but **cannot eliminate** them completely
- Mechanical considerations in
  - Sizing vessels
  - Piping layout
  - Clamping
  - Small bore attachments

Mechanical Natural Frequency (MNF)

- Frequencies where small forces result in large vibration response of structure
- Even small forces at MNF can cause significant amount of vibrations, which can lead to fatigue failures

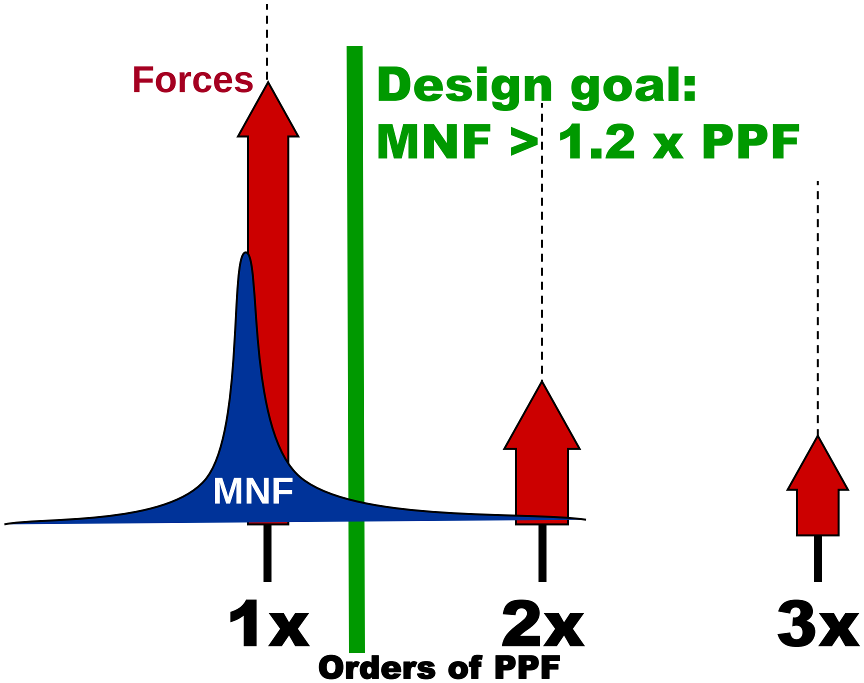




Force & MNF in Reciprocating Pumps

Most pulsation induced forces occur at

Plunger Passing Frequency (PPF)=
RPM X Number of Plungers



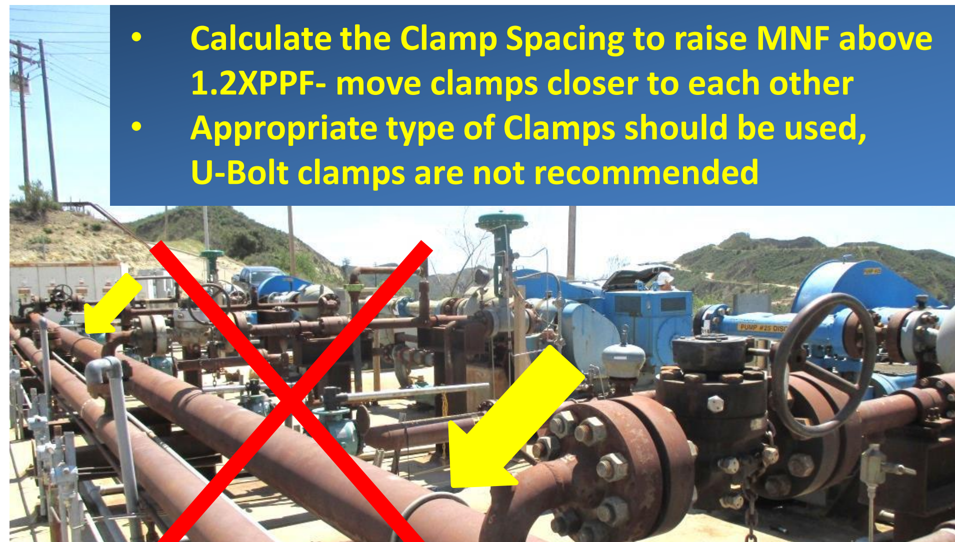
API 674:
Minimum MNF must be **greater than 20% above PPF**

Example: Clamps

PROBLEM: High Vibrations

Shoe type and rest-only pipe supports good for thermal loads, but cannot restrain dynamic loads of reciprocating pumps

All clamps must have proper foundation



- **Calculate the Clamp Spacing to raise MNF above 1.2XPPF- move clamps closer to each other**
- **Appropriate type of Clamps should be used, U-Bolt clamps are not recommended**

Design tip: Perform a full API 674 mechanical review at the design stage

Note: Vibration and thermal pipe stress concerns can both be accommodated.

Example: Piping Layout

PROBLEM: High Vibrations

- **Route piping as close as possible to the foundation**, so it can be easily supported
- **Additional friction and head loss will affect system resistance curve – but recips will easily make up the pressure**.

Example: Small-Bore Attachments (SBA)

PROBLEM: Small-Bore Failure

- About 70% of leaks are due to SBA failures
- Stress concentrations (threaded connections are trouble)
- Eliminate if possible
- Shorten as much as possible
- Add braces to main pipe (not to foundation)

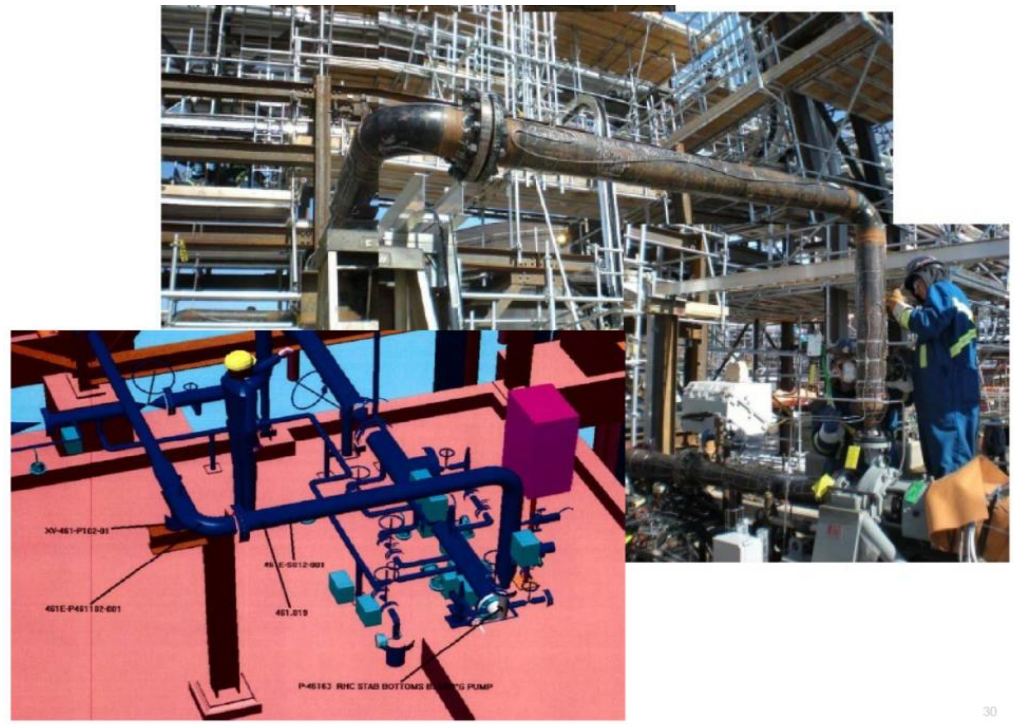
Design tip: If a SBA cannot be eliminated, shorten the length as much as possible or brace it back to the main pipe

Eliminate Christmas trees!

Piping Design for Centrifugal Pump Piping Systems - Summary

Design Approach (Centrifugals)

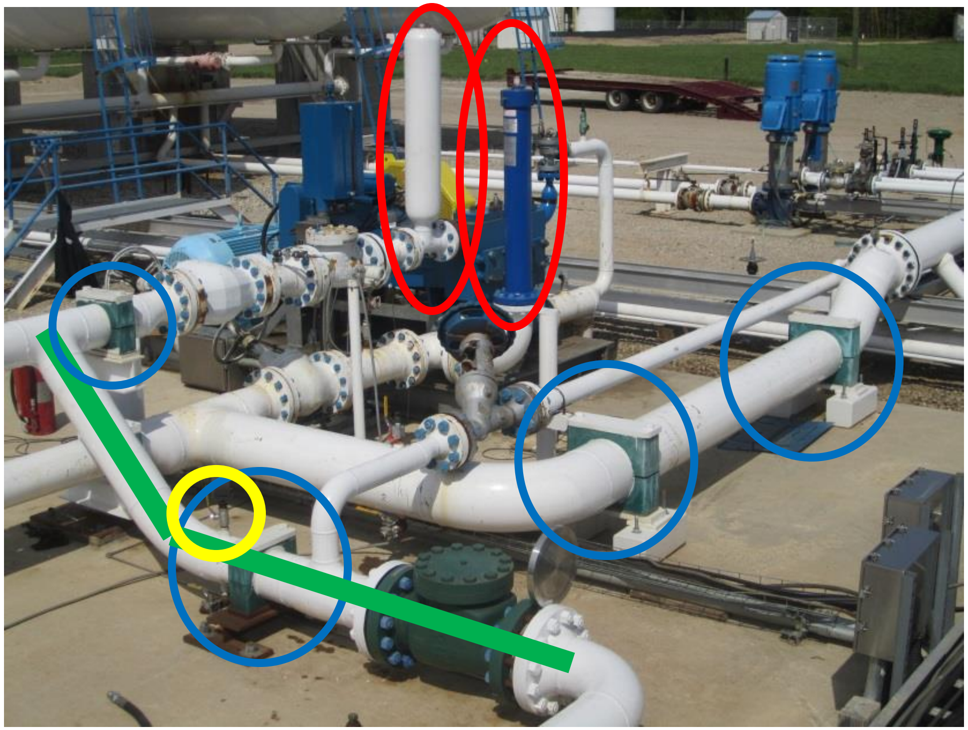
- Designed mainly for static and thermal loads
- Pipe supports to restrain dynamic loads, generally not required
- Hanger and piping shoes are common



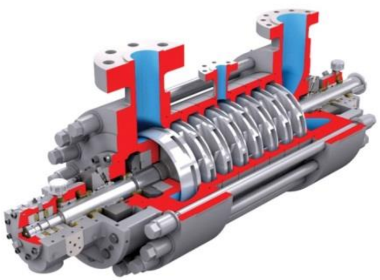
Piping Design for Reciprocating Systems - Summary

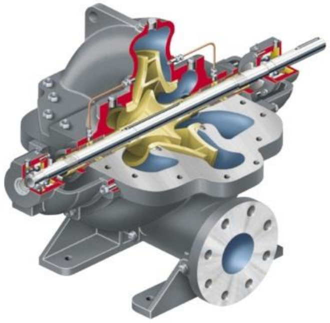
- Pulsation dampeners and other pulsation control devices generally required
- API 674 Pulsation Design Study often necessary
- Piping supports should be designed to restrain large dynamic loads
- Hold-down type clamps
- Clamps at different locations to raise MNF above 1.2X PPF
- Piping layout close to foundation
- Eliminate or shorten small bore attachments as much as possible

Reciprocating



Case Study

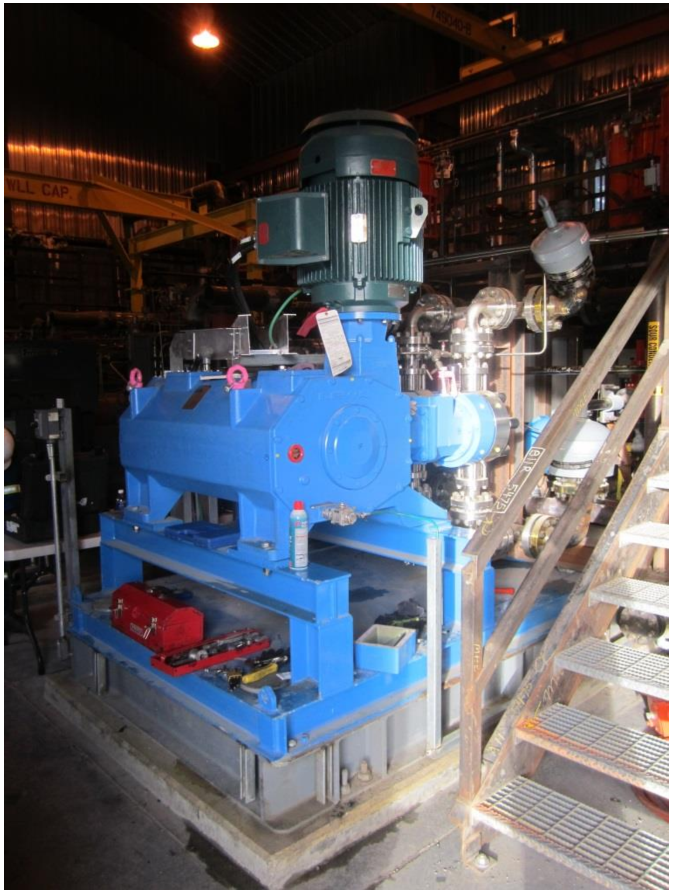




Case Study: What's the problem?

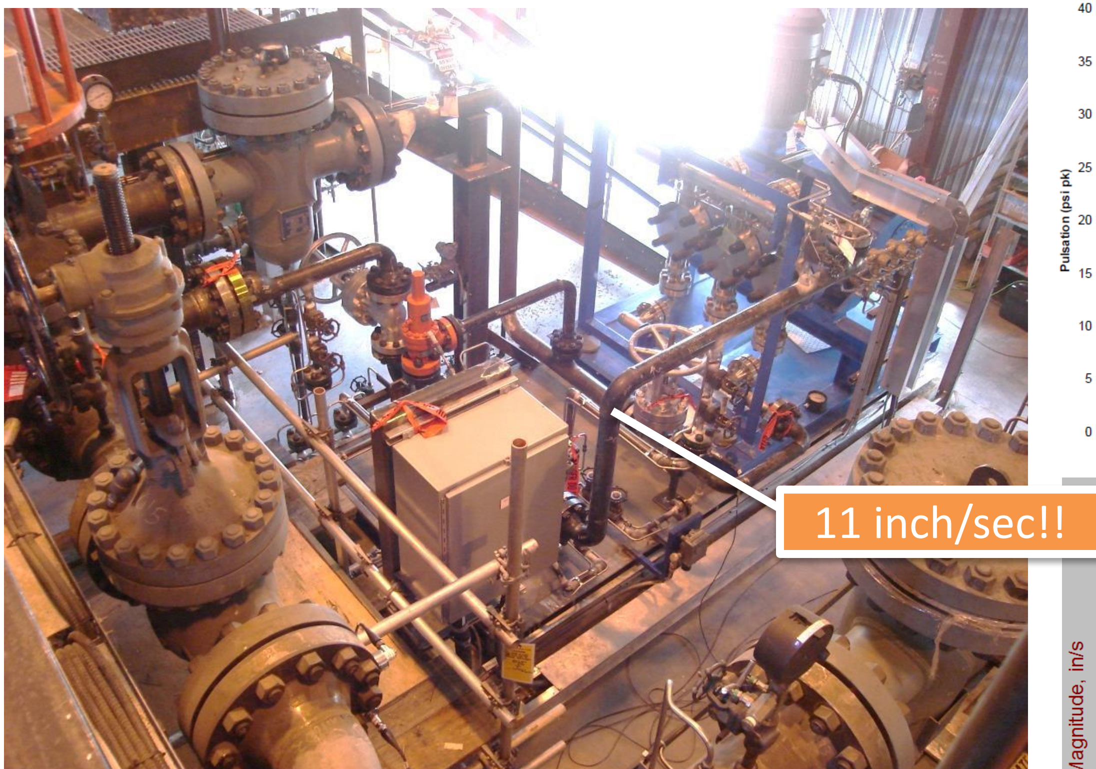
BACKGROUND:

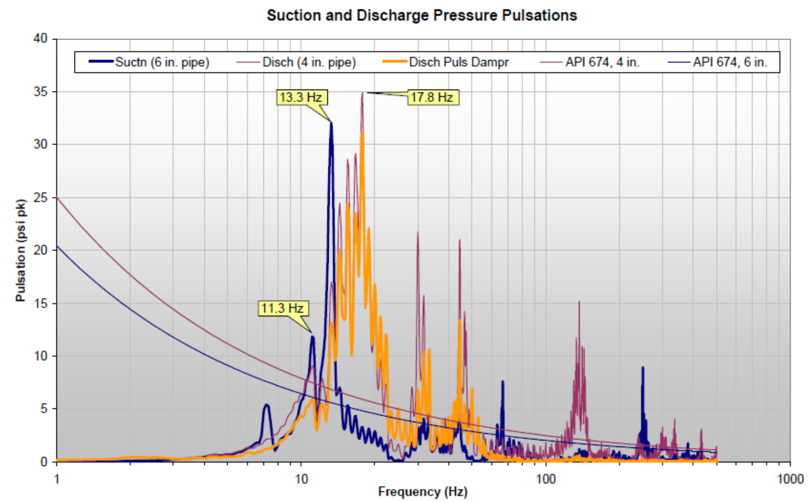
1. Field pressure depleting
2. Existing centrifugal pumps highly oversized, high recycle
3. Why not replace centrifugal pumps with a small recip?
4. A triplex diaphragm pump was installed (no pulsation or mechanical study done)
5. Could not be operated due to vibration and pulsation problems!

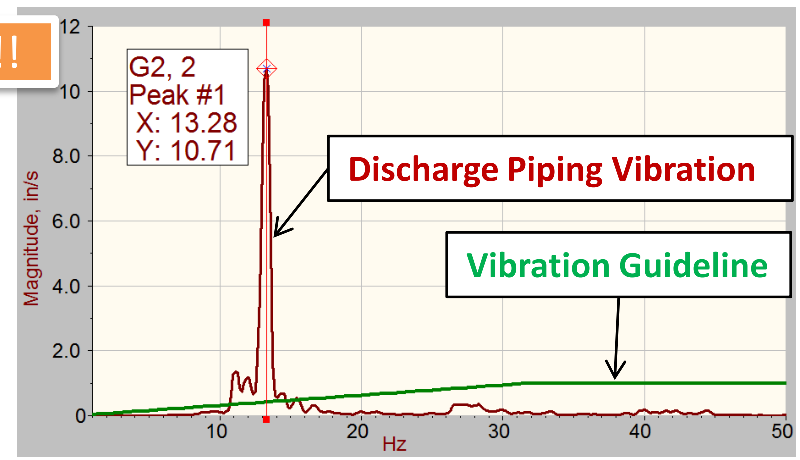


Case Study: Video

Vibration and Pulsation Measurements

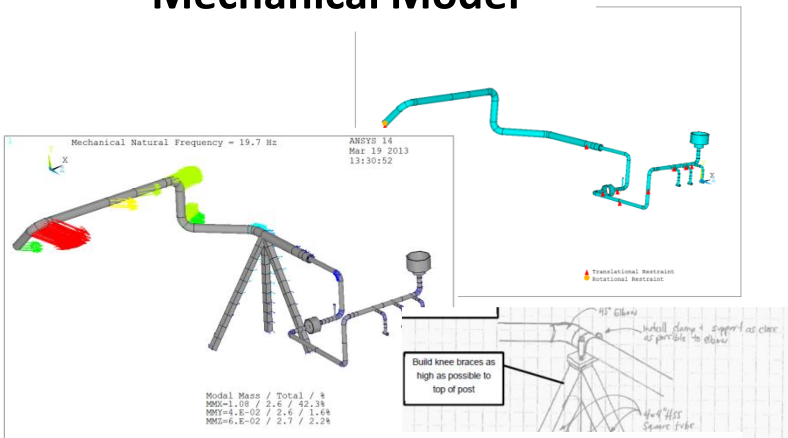




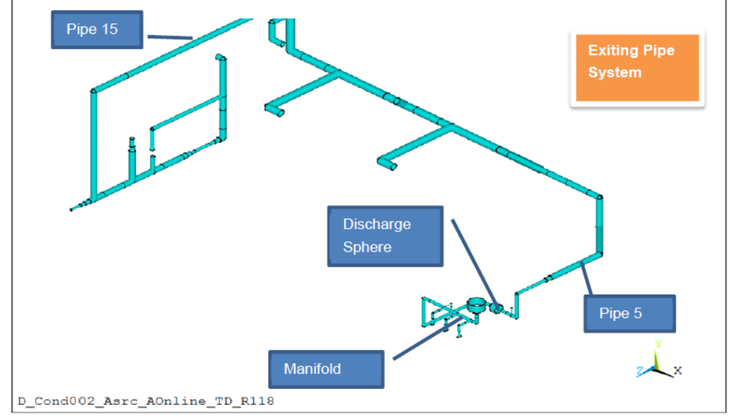


Case Study: Pulsation and Mechanical Analyses

Mechanical Model



Pulsation Model



Mechanical Recommendations

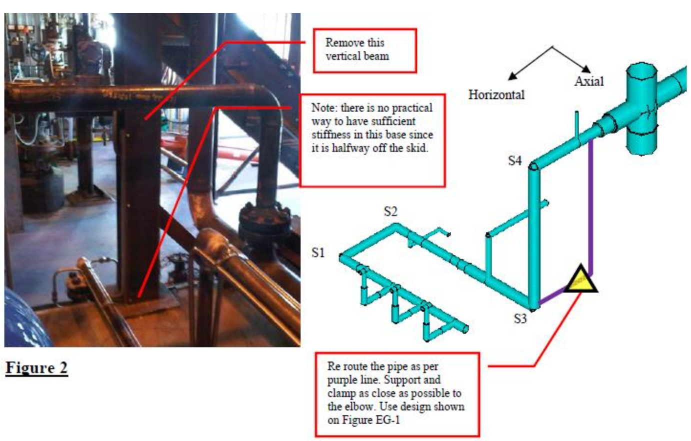
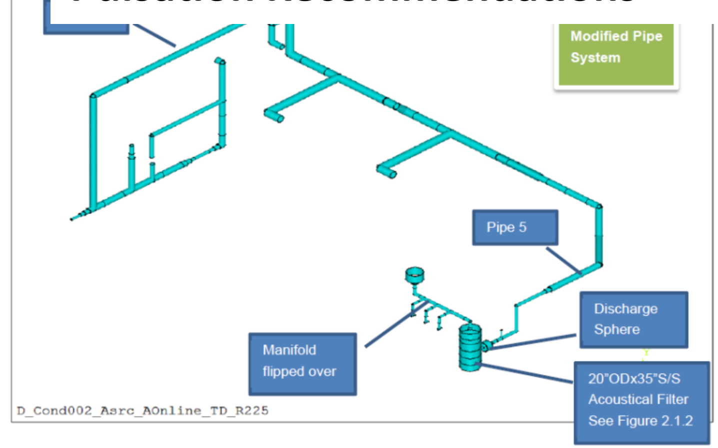
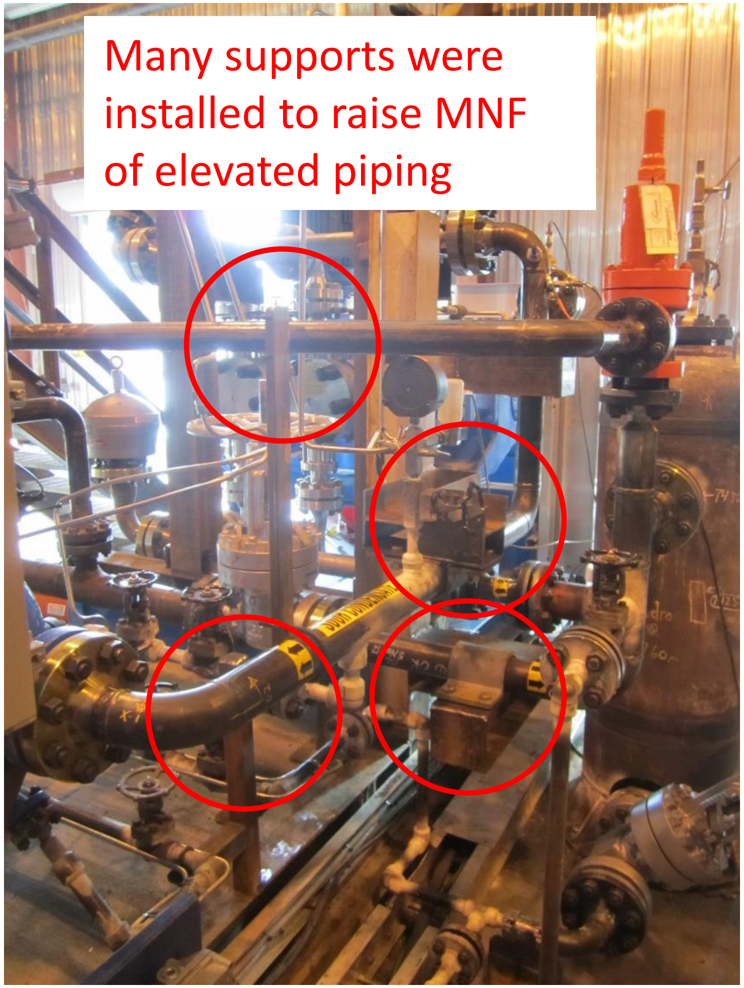


Figure 2

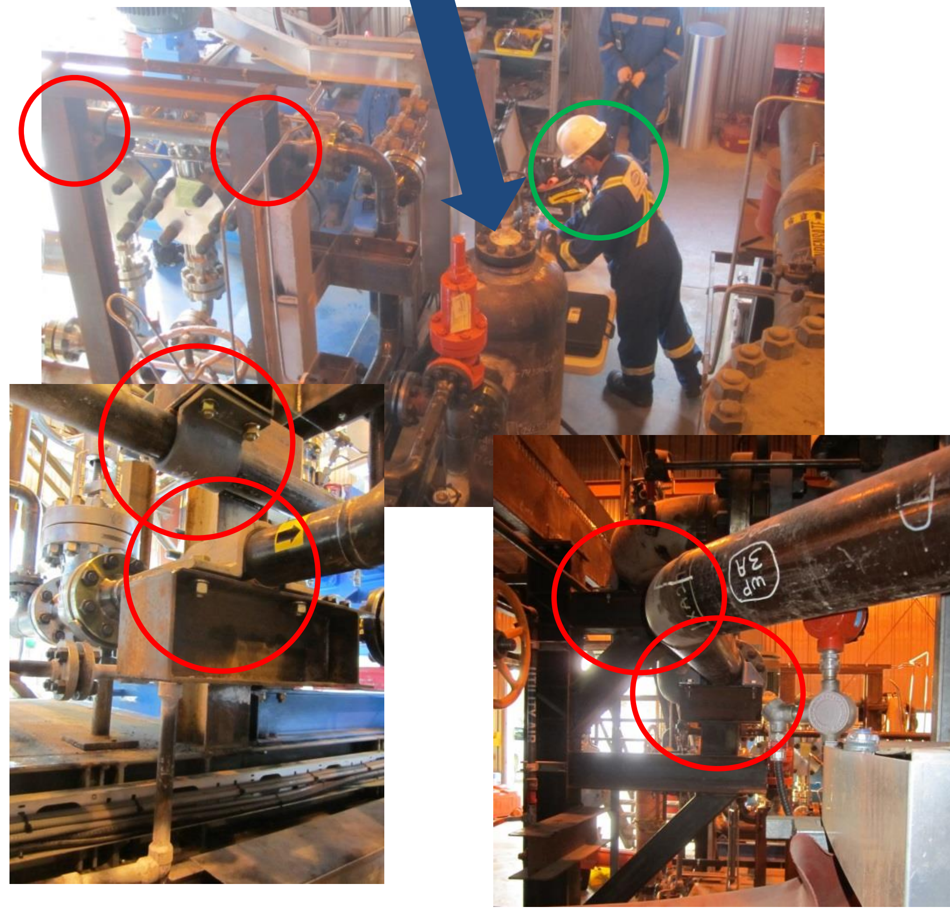
Pulsation Recommendations



Case Study: Recommendation Implementation



Additional pulsation dampener



Wrap-Up

Conclusions

Reciprocating Pumps generate high pulsation-induced forces in piping.

- Therefore, piping design concepts for centrifugal pumps should NOT be applied to reciprocating pumps
- Reciprocating Pumps can work well, they just have to be designed well

For Reciprocating Pumps:

1. Pulsation Dampeners are required
2. API 674 Design Study is often necessary (DA1, DA2, or DA3)
3. Pulsations should be controlled and minimized at design stage
4. Piping layout should be as close as possible to foundation for best support
5. Vibration and thermal pipe stress concerns can be both addressed for a good design.
6. Generally piping requires more support (including vibration clamps)
7. Hangers, rest-only supports, and pipe shoes cannot restrain high pulsation induced shaking forces
8. Eliminate, reduce height, or brace small bore attachments

QUESTIONS?

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