Best Practices for Specifying & Procuring a Successful Large, High-Speed Reciprocating Compressor Package

2014 Gas Machinery Conference
Short Course

Norm Shade, ACI Services Inc.
Josh Shaver, Atmos Energy
Brandon Durbin & Dave McCoy, Ariel Corporation
Ken Hall & David Krenek, Caterpillar
Frank Northrup, SEC Energy Products
Kelly Eberle, Beta Machinery Analysis

Best Practices for Specifying & Procuring a Successful Large, High-Speed Reciprocating Compressor Package

- Introduces GMRC High Speed Compressor Package Guideline (soon to be released)
- Provides an initial (brief) overview & introduces some best practices.
- Intended to be the1st installment of a 3-day GMRC course that will provide much more detail (to be introduced in 2015)

Course Content & Schedule

Introductions & Overview *(Norm Shade)* **8:00**
Background – GMRC HS Package Guideline Project
What's a good project look like?
Who's in charge?
Introduction to the GMRC Guideline

End User Perspective *(Josh Shaver)* **8:40**
Best practices – what works?
What to avoid/doesn't work

Compressor Considerations *(Dave McCoy/Brandon Durbin)* **8:55**
Compressor Mounting & Equipment Installation
Compressor Drain & Vent System Best Practices

BREAK **9:25**

Course Content & Schedule

Engine Considerations *(Ken Hall)* 9:35
Engine Selection (fuel, site conditions
TVA Validation of driveline
Engine mounting & Alignment
Engine external connections

Packager Perspective *(Frank Northrup)* 10:05
What's important from packager perspective?
What's needed from the purchaser?
When is it needed?
Best practices

System Design Considerations *(Kelly Eberle)* 10:20
System Design Considerations
Best practices
Other

Summay & Wrap Up 10:45
Q/A & Open discussion
Wrap Up Summary

Adjourn 11:00

DISCLAIMERS

DISCLAIMERS (continued)

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Background – GMRC HS Package Guideline Project

Large (≥2000 hp), High-Speed (>700 rpm) Reciprocating Compressors (for Gas Pipeline & Storage Applications)

Desirable Features

- Lower capital cost than slow speeds
- More compact than slow speeds
- Shorter lead time (manufacturing & installation)
- Currently produced at reasonable volumes – modern technology
- Multiple suppliers, good parts availability & support
- Multiple driver options with good efficiency and environmental compliance
- Use is increasingly common

Background – GMRC HS Package Guideline Project

Large (≥2000 hp), High-Speed (>700 rpm) Reciprocating Compressors (for Gas Pipeline & Storage Applications)

All Too Frequent Issues with the Installed System

- High vibration
- High pulsation levels
- High system losses (pressure drop) reduce system efficiency
- Poor accessibility for maintenance
- Failures of ancillary components and systems
- Inability to deliver design throughput

Background – GMRC HS Package Guideline Project

Challenges Associated with Large, High-speed Compressors

- Available specifications are of limited value
- Broader spectrum of pulsation frequencies that must be addressed
- Lighter frames and I-beam skid mounting tend to be more flexible and reactive than traditional heavier, slow speed block-mounted compressors
- Higher frequency pulsation dampening increases piping system pressure losses
- More sophisticated methods of pulsation and vibration modeling and analyses are required.
- New pulsation control "tools" and best practices for damping, de-tuning, and/or cancelling pulsations may be necessary.
- Compressor /driver systems are most commonly supplied by a third party systems integrator (packager); not the compressor OEM.
- MORE>>>>

Background – GMRC HS Package Guideline Project

Challenges Associated with Large, High-speed Compressors

- Packager experience derived from upstream applications where efficiency and flexible control are usually not prime considerations.
- Supply chain behavior driven by economic factors.
- Shared responsibility for final product's performance.
- Pressure to shorten delivery schedule creates risks/problems…..not enough time to coordinate and address some of the key design requirements.

Background – GMRC HS Package Guideline Project

Sometimes we're so pre-occupied with what we're doing that we don't see disaster coming our way!

☺

Background – GMRC HS Package Guideline Project

Background – GMRC HS Package Guideline Project

GMRC HS Package Guideline Development Program

- 13 companies provided all funding for 2 year program

2011

- Assessment of field problems, solutions & best practices
- Extensive surveys & interviews
  - 12 end user companies
  - 8 compressor & driver OEMs
  - 4 packagers
  - 5 engineering companies
  - 11 site visits including 30 large units
- Literature research
- Team member experience
- Summary report and outline of Guideline

2012

- Vibration/Pulsation Subcommittee – best practice consensus
- Guideline development
  - Applicable to Pipeline & Storage Applications
  - >2,000 HP & ≥ 700 rpm

2013

- Guideline finalized, reviewed and released

Lots of Problems Observed – Vibration Related Failure Examples

Shows need for some key design requirements.

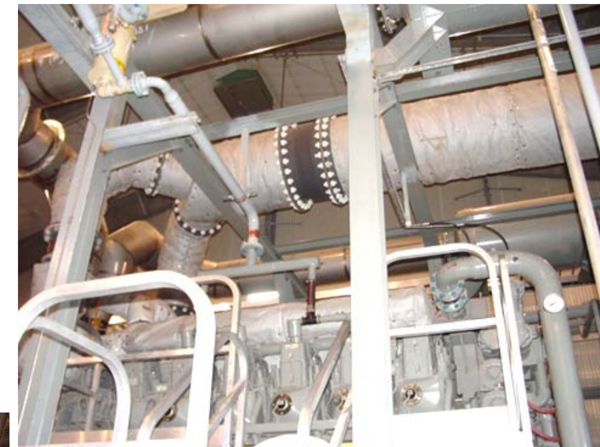
Background – GMRC HS Package Guideline Project

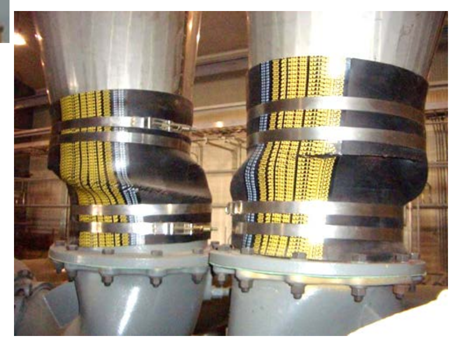
Lots of Problems Observed – Vibration Related Failure Examples

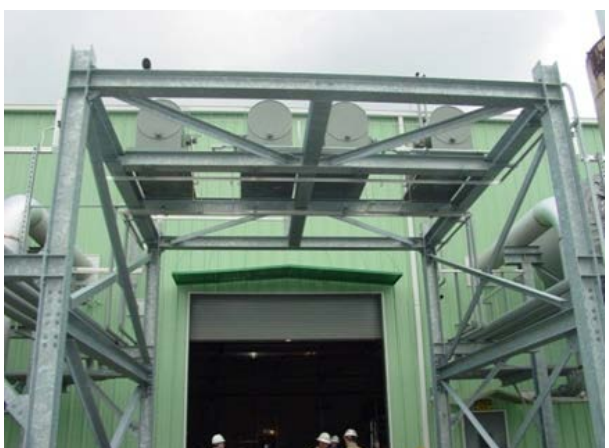
Shows need for some key design requirements.

Lots of Problems Observed – Alignment/Access/Maintainability

Shows need for some key design requirements.







Lots of Opportunities for Improvement

- Document & Communicate Best Practices
- Develop new solutions were needed
- Define what is required of new systems before purchasing them
- Apply sound engineering design
- Appropriate bid and purchase specifications
- Realistic and properly sequenced project plan and schedule
- Oversight and closing the loop on details

What's a Successful Project Look Like?

- An "appropriate" spec is provided that defines critical requirements and accountabilities, while leaving flexibility for packagers to apply their experience where applicable.
- A project manager is assigned by the end user, either an experienced employee or experienced consultant.
- A range of operating conditions is provided plus key design points. This should include expected intentional as well as potential unintentional (but possible) operating ranges over which the equipment may be operated. Ideally, this is part of the pre-order process, but as a minimum, it must be part of the design process.
- Compressor loading and operating requirements are defined considering required operational flexibility and pulsation/vibration concerns, not just a limited number of compressor design point checks.
- The plant engineering company (EPC) is brought in as early as possible.
- The package or the packager is not treated as a commodity. One or more packagers are pre-qualified and the end user continues to work with them as long as expectations are met.
- The pulsation and vibration consultant is selected and involved early in (or even before!) the design process.
- The piping layout is available for review early in the project.

MORE>>>>>>>>>>>>

Plan, Plan, Plan…………………..!

What's a Successful Project Look Like?

- The EPC and packager provide the required information to enable the pulsation and vibration analyses to begin as early as possible. The off skid information becomes available later during the project – and the design is then adjusted to ensure off-skid issues are addressed.
- Ideally the pulsation and vibration consultant works directly for the end user or its representative to ensure that reliability/vibration goals are met and decisions requiring efficiency and reliability trade-offs are made prudently and quickly.
- The end user stays involved in the project, especially at key meetings (those that establish scope, kick-off, review findings and analysis recommendations).
- Reasonable time lines are established to complete the design and prepare vibration recommendations (e.g., 1 week turnaround for preliminary bottle sizes, 3 weeks for adequate pulsation analysis, mechanical analysis, collaboration with packager, assess alternatives, prepare drawings/recommendations, fabrication).
- An inspector is assigned by the end user for the compressor fabrication phase at the packager's plant.
- An inspector follows the installation and connection of equipment on site.

"A spec is a communication document.
There are lots of unspoken expectations.
If the spec can bring them to light, it will be effective."

Who's In Charge?

Project Manager

- A project manager should be assigned by the end user, either an experienced employee or qualified consultant.
- The end user's representative(s) should be involved in regular reviews during the design and fabrication processes.
- The project manager should review the results of the pulsation and vibration analyses as they progress, to ensure that appropriate trade-off decisions are made between efficiency, reliability, and cost.

Inspector

- An inspector should be assigned by the end user for the compressor fabrication phase at the packager's plant. Ensures scope is followed, surprises are avoided and quickly resolved, and packager maintains quality throughout.

Installation & Commissioning Coordinator

- An experienced coordinator or supervisor should be assigned by the end user for the compressor installation on site through the start up and commissioning phases.

Communicate…Oversee…Communicate…Execute Successfully!

Some More Food For Thought….

- The guideline defines the scope, requirements, and expectations. A risk assessment is recommended to evaluate vibration risk on the project. This determines the recommended scope for the vibration analysis.
- A fixed speed machine will have fewer vibration problems than when a machine is required to operate over a wide speed range. Vibration risk is much higher for a wide speed range.
- Reasonable HP/throw. If the compressor requires maximum HP/throw (compared to rated values), then the unit will have higher gas forces (cylinder stretch) issues.
- For large, more critical applications, the scope of work includes API 618 Design Approach 3 (DA3) including forced response of compressor manifolds.
- All significant forces must be included in the analysis.

And More Food For Thought….

- Torsional vibration analysis on all large units unless a mechanical and operational duplicate of a unit already analyzed. Consider effects of manufacturing tolerances.
- Vibration consultant to address thermal design and mechanical design (to avoid conflicting pipe support assumptions and thermal and vibration requirements).
- Evaluate the performance impacts for the compressor and piping system, including coolers, headers, and other piping. Ensure the pressure drop through vessels and piping is included in the performance calculations. Checking "system performance" at key conditions will avoid surprises and unexpected flow or power issues.
- Use a well-designed foundation. For large units, a concrete block has advantages. If not, the skid design must be evaluated in more detail. A dynamic foundation analysis is recommended for large (critical) machines.
- Effective mounting and installation is critical.
- Ensure that packager and staff experience are appropriate for the project.

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Project Organization Questions?

GMRC HS Package Guideline - Introduction

GMRC GUIDELINE FOR HIGH-SPEED
RECIPROCATING COMPRESSOR PACKAGES
FOR NATURAL GAS TRANSMISSION
& STORAGE APPLICATIONS

RELEASE 1.3
07/19/13

Gas Machinery Research Council
ACI Services Inc.

GMRC Gas Machinery Research Council est 1952 ACI Services, Inc.

Basis for this short course.
Copies available for purchase at:
http://www.gmrc.org/hs-guidelines

GMRC HS Package Guideline - Contents

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7. PULSATION AND VIBRATION ANALYSIS & CONTROL (*continued*)

GMRC HS Package Guideline - Contents

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ANNEX

LIMITATIONS / RECOMMENDED USE OF THE GUIDELINE

- Not intended to be an all-inclusive specification.
  - Many features are project, end user and packager specific.
  - Some end users and packagers have their own preferred designs and standards.
  - Beyond the scope of this Guideline to reconcile every last detail of a potential specification.
- Unlike API, ISO and ASME, the GMRC does not issue standards and official specifications.
- Information contained herein provides a set of guidelines and what the study results reflect as good practices,.
- Intended to serve as a suggested tutorial for the design, installation and operation of high-speed reciprocating compressor packages for natural gas transmission and storage applications.
- End users are encouraged to use the information in this Guideline to develop their own detailed specifications.

Full coverage of the Guideline requires a 3 day course (available next year).

In this <3 hour "short" course, we attempt to highlight some key issues from the most of the sections as shown below.

Section	1	2	3	4	5	6	7	8	9	10	11	12	13	14	App
Overview	X	X	X							X		X	X		X
End User		X	X									X	X		
Compressor OEM						X	X		X	X	X		X		
Engine OEM			X		X	X	X		X				X		
Packager		X	X					X			X				
Designer & Analyst		X				X	X					X	X		

GMRC Guideline - Questions?

End User Perspective

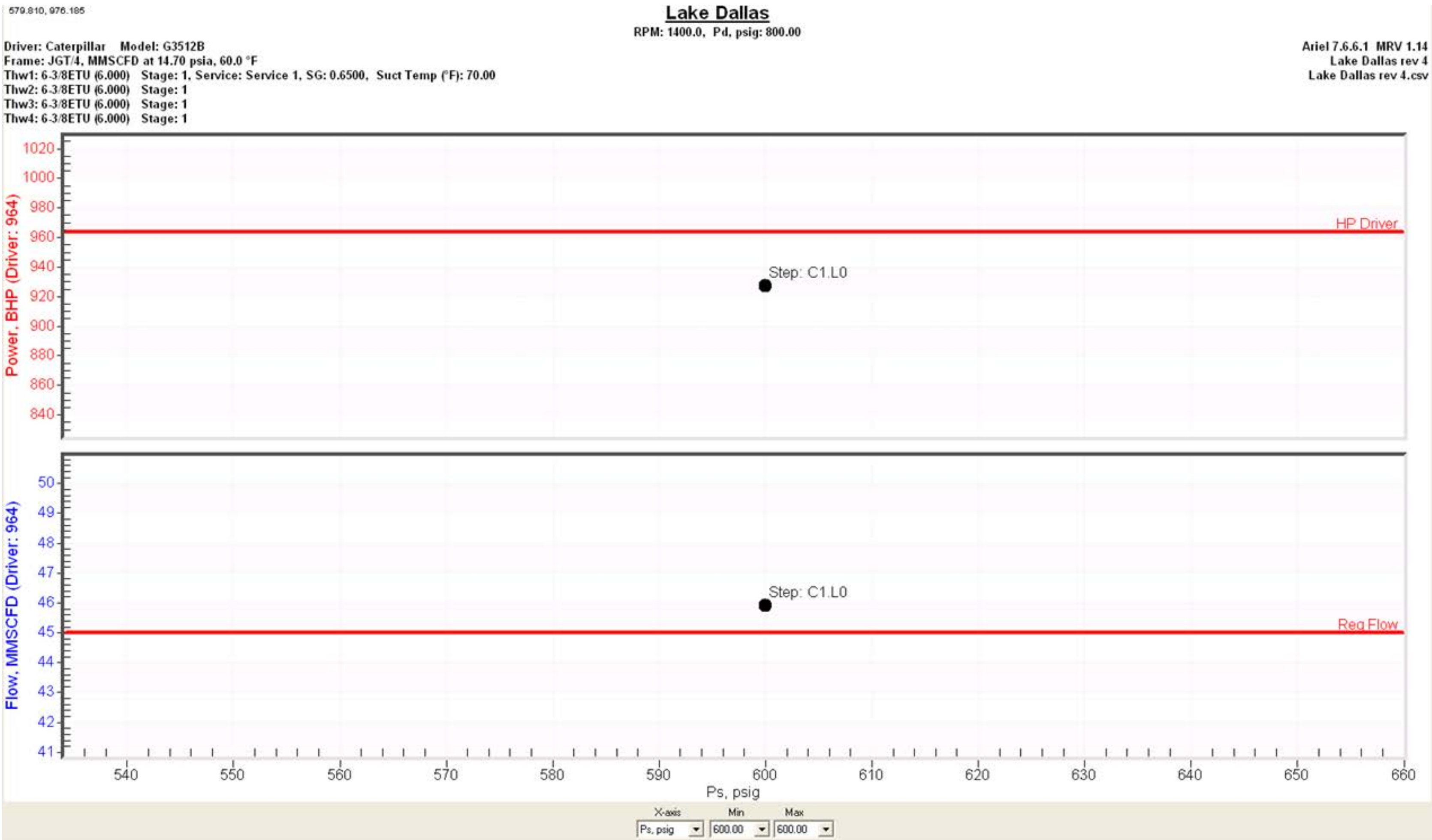
Josh Shaver, Atmos Energy

End User Perspective
What Works? Attention to Detail

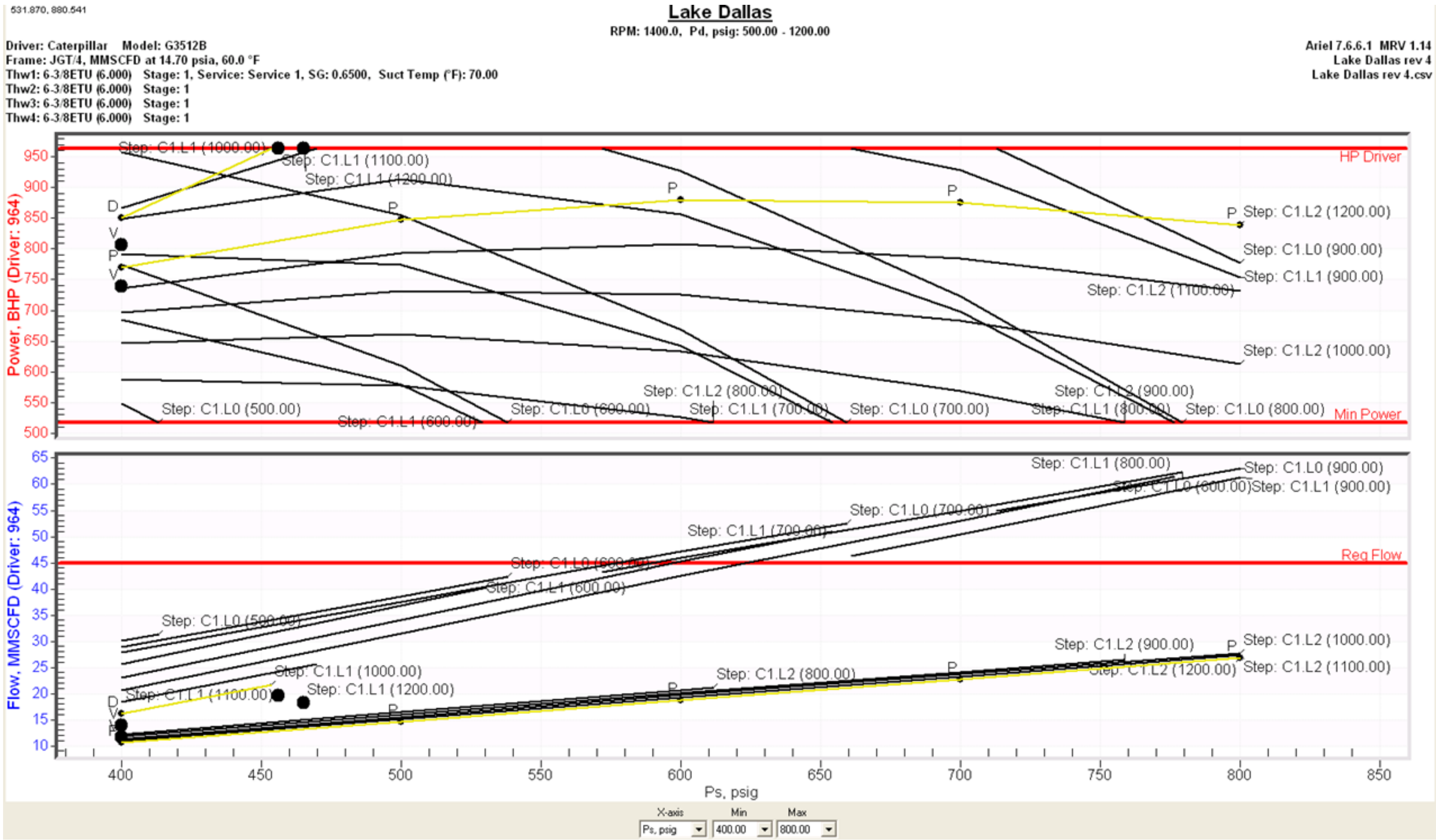
Design Conditions

- Design point
- Operating range
- Future capacity growth or reduction
- Sanity check

End User Perspective
What Works? Attention to Detail



End User Perspective
What Works? Attention to Detail



Best Practices for Specifying & Procuring a Successful Large, Hi-Speed Reciprocating Compressor Package

End User Perspective
What Works? Attention to Detail

Size & Select Equipment

- Process requirements
- Value (hp/$, features/$)
- Operability
- Internal discussions
- Analysis

End User Perspective
What Works? Attention to Detail

Spec / Bid / Purchase

- **Analyze**
  * Skid
  * Foundation & Soil
  * Acoustics
  * Piping
  (thermal, vibration, occasional)
- **Spec Creation**
  * lessons learned
  * internal discussions
  * details

ATMOS energy	PIPELINE SERVICES EQUIPMENT SPECIFICATION SKID MOUNTED RECIPROCATING NATURAL GAS ENGINE/COMPRESSOR PACKAGE	Spec. No. X#### Skid Compressor Package Created By: JAS Rev. No. 0 Rev. Date 09-15-2010 Page 1 of 38

End User Perspective
What Works? Attention to Detail

		Atmos Spec	Score	Bid 1	Score	Bid 2	Score
	††General 3.0						
	Engine	CAT 3512B	20	Atmos Spec	20	Atmos Spec	20
	Compressor Frame	Ariel JGT/4	20	Atmos Spec	20	Atmos Spec	20
	Compressor Cylinders	6 3/8"TU (6.000" Bore)	10	Atmos Spec	10	Atmos Spec	10
	Ambient	105 F	20	Atmos Spec	20	Atmos Spec	20
	Altitude	500 ft	20	Atmos Spec	20	Atmos Spec	20
	††Engine 4.0						
	Engine Emissions 4.4	.5 Nox, 2.0 CO, .7 VOC, EPA, TCEQ	10	Atmos Spec	10	Atmos Spec	10
	Engine Starter 4.8	150 psig Turbine, Full Load Start	10	Atmos Spec	10	Atmos Spec	10
	Fuel Gas 4.9	150 psig supply, FG scrubber	10	Atmos Spec	10	Atmos Spec	10
	††Compressor 5.0						
	Compressor Packing Vents 5.7	To Match Figure 1	10	Atmos Spec	10	Atmos Spec	10
	Pneumatic Unloading Devices 5.8	Provided by Vendor	10	Atmos Spec	10	Atmos Spec	10
	Kim Hot Start Heater for Compressor Oil 5.10	480/3/60 Power, 24 VDC on/off	10	Atmos Spec	10	Atmos Spec	10
	††Torsional Analysis 6.0						
	Torsional Analysis 6.0	Purchased Separately by Atmos	10	Atmos Spec	10	Atmos Spec	10
	††Coolers 7.0						
	Coolers Configuration 7.1.1	Skid Mounted, Engine Driven	10	Atmos Spec	10	Atmos Spec	10
	Cooler Noise 7.1.8	10,000 fpm, 85 dBA	10	Atmos Spec	10	Atmos Spec	10
	EJW / AW Coolers 7.2	110% Surface	10	Atmos Spec	10	Atmos Spec	10
	††Gas Piping 8.0						
	Acoustic and Mechanical Studies 8.2	Purchased Separately by Atmos	10	Atmos Spec	10	Atmos Spec	10
	Gas Pipe spec's and Standards 8.3	F = .04, S/D MAOP = 800/1200 psig	10	Atmos Spec	10	Atmos Spec	10
	Compressor Bottles 8.4	Sized per API 618, ASME	10	Atmos Spec	10	Atmos Spec	10
	††Skids 9.0						
	Vibracon Mounts 9.2	Not Acceptable	10	Atmos Spec	10	Atmos Spec	10
	Skid Top checkered steel plate 9.9	Seal Welded Over Entire Top of Skid	10	Atmos Spec	10	Atmos Spec	10
	Skid Oil Containment 9.11	Drip Lip, Skid Drains	10	Atmos Spec	10	Atmos Spec	10
	††Package Instrumentation and Electrical 10.0						
	Package Instrumentation and Electrical 10.0	To Match List in Appendix C	10	Atmos Spec	10	Atmos Spec	10
	††General 11.0						
	Painting 11.1	Prep, Paint, Primer. High Temp Exhaus	10	Company Standard	0	Company Standard	0
	Inspection 11.3	Atmos has Right to Inspect at Any Tim	10	Atmos Spec	10	Atmos Spec	10
	††Documentation 13.0						
	P&ID 13.1	30 Days ARO	10	Not Supplied for Approval	0	8 Weeks ARO	0
	Auto CAD 13.2 & 13.6	30 Days ARO	10	Not Supplied for Approval	5	2-4 Weeks ARAD, Prelim 30 Days ARO	5
	Job Books 13.4	Provided by Vendor	10	CD	10	CD	10
	Code Compliance Book 13.5	30 Days Prior to Shipment	10	Not Supplied	10	Atmos Spec	10
	*Technical notes	- List specific experiences from a technical perspective, feedback, quantity/quality of work	+/-		-20		0
	Subtotal		320		275		295
Commercial	Bid Price	Lowest	180	$1,070,660	180	$1,174,809	164
Commercial	T's & C's	Atmos STD	40	10/25/20/30/15	40	15/25/25/25/10	40
Commercial	Lead Time	Lowest	180	30 Weeks ARO	162	26-28 Weeks ARO	180
Commercial	*Commercial notes	- List specific experiences from a commercial perspective, feedback, accuracy of bids, size/frequency of ECR's	+/-		0		0
Commercial	**Subtotal**		400		382		384
	Total		720		657		679
	%		100.0%		91.3%		94.3%

Spec / Bid / Purchase

- **Bid**
  - * spec review with bidders
  - * exceptions, clarifications
  - * bid tab, evaluation

Purchase

- * issue PO with revised spec, bid, contract, all supporting docs
- * project kick off meeting
- * establish expectations

End User Perspective
What Works? Attention to Detail

Fabrication
- **Inspector**
  * In shop for duration
- **Company witness for key events**
  * Witness to be operator, engineer or project manager
  * Equipment grouting
  * Run test

Installation
- **Inspector**
  * On site for duration of construction
- **Company witness for key events**
  - To be operator, engineer or project manager
  - Run test

Commissioning
- Verify expectations are met
- Actual performance vs. expected performance

End User Perspective
What Works? Attention to Detail

Lake Dallas Storage: Two compressors being added, horizontal well to be drilled

Two new high-speed natural gas compressors are being installed at the Lake Dallas underground storage facility south of Denton. The $18 million project adds to an existing compressor. Each new unit is 12 feet wide, 35 feet long and 15 feet tall.

"The compressor expansion will allow us to go from 15 MMcf (million cubic feet) per day to 90 MMcf per day injection capacity once all the enhancements are complete," said Operations Vice President Bharat Trivedi. "Lake Dallas' total reservoir capacity is 4.3 Bcf with a working gas capacity of about 3 Bcf. The new compressors should be ready to go by December."

Construction approvals have slowed the project, says Storage & Compression Manager Marlan Jarzombek.

"Since this project is within the city limits of Denton, we have gone through a rigorous permitting process, obtaining approvals from the city. Employees from engineering, right of way, and construction teams have worked hard and recently obtained the permitting to go vertical so we can install the supporting facilities around the compressors. We are hoping to get the office control room approved soon. We expect all the enhancements to be completed in 2012, including a new well and dehydration equipment."

There are currently eight wells at Lake Dallas; a ninth will be drilled later this year. The 1,500-foot horizontal well will be drilled in the sandstone formation.

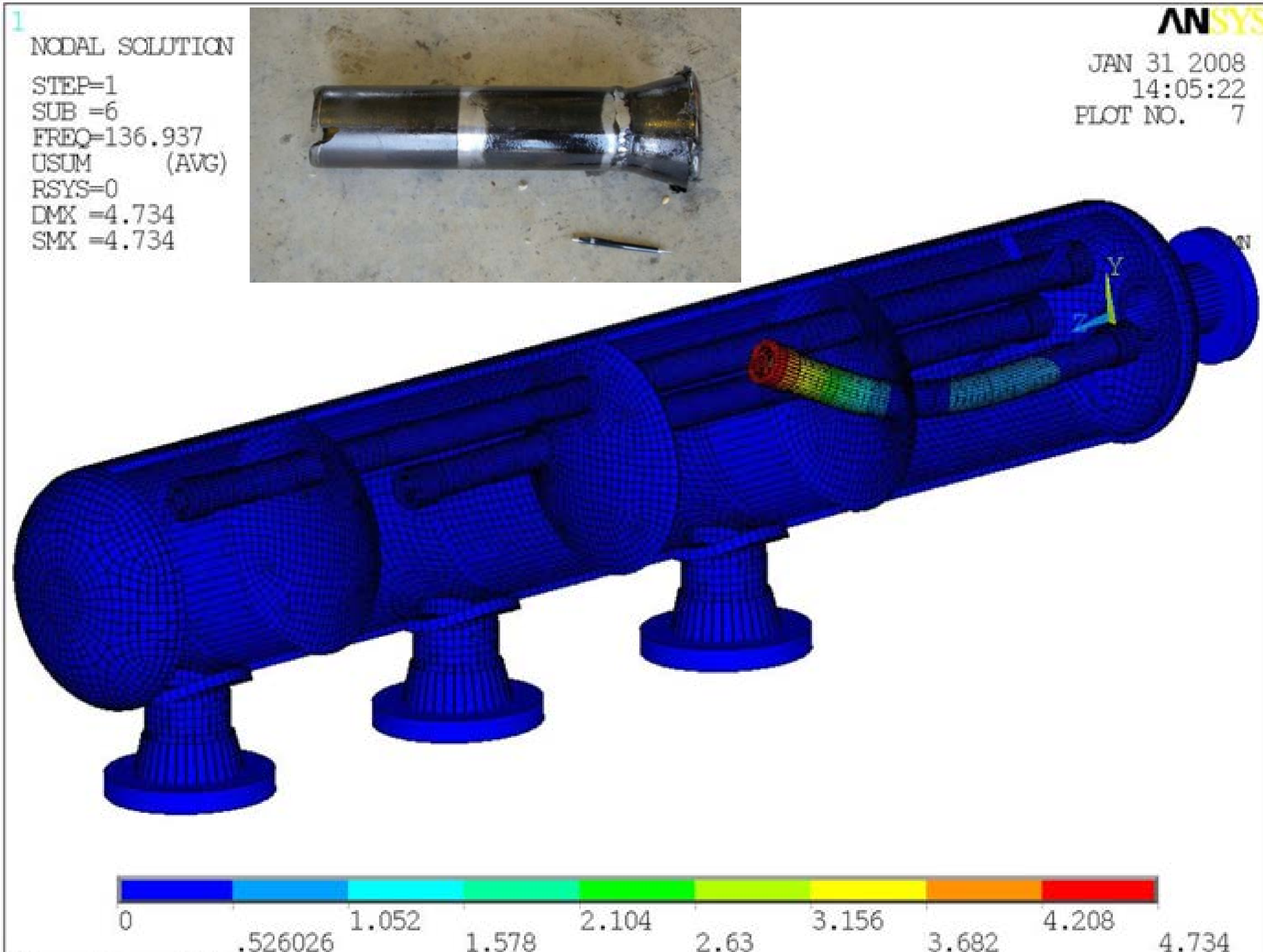
At the Lake Dallas underground storage facility, Engineer Josh Shaver (left) and Operations Supervisor Mark Williams discuss one of two new high-speed compressors.

"Jerry Han, Kevin Bush and Gary Rains of the Reservoir Group recently completed a seismic survey and mapped the formation in 3D," Jarzombek said. "A path will be tracked through the formation, optimizing the well design so that injection and withdrawal capacities will be fully maximized utilizing the existing Strawn Sand reservoir."

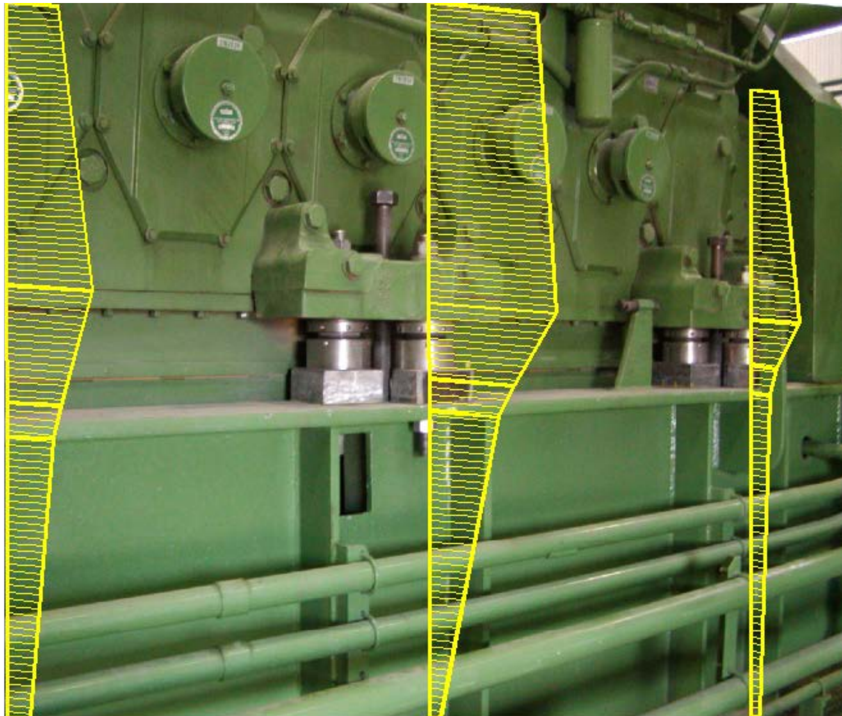
"Once the injection, piping and well enhancements are complete, 90 MMcf total injection capacity should be achieved," Trivedi said. "Withdrawal capacity is expected to increase from 120 MMcf to 170 MMcf."

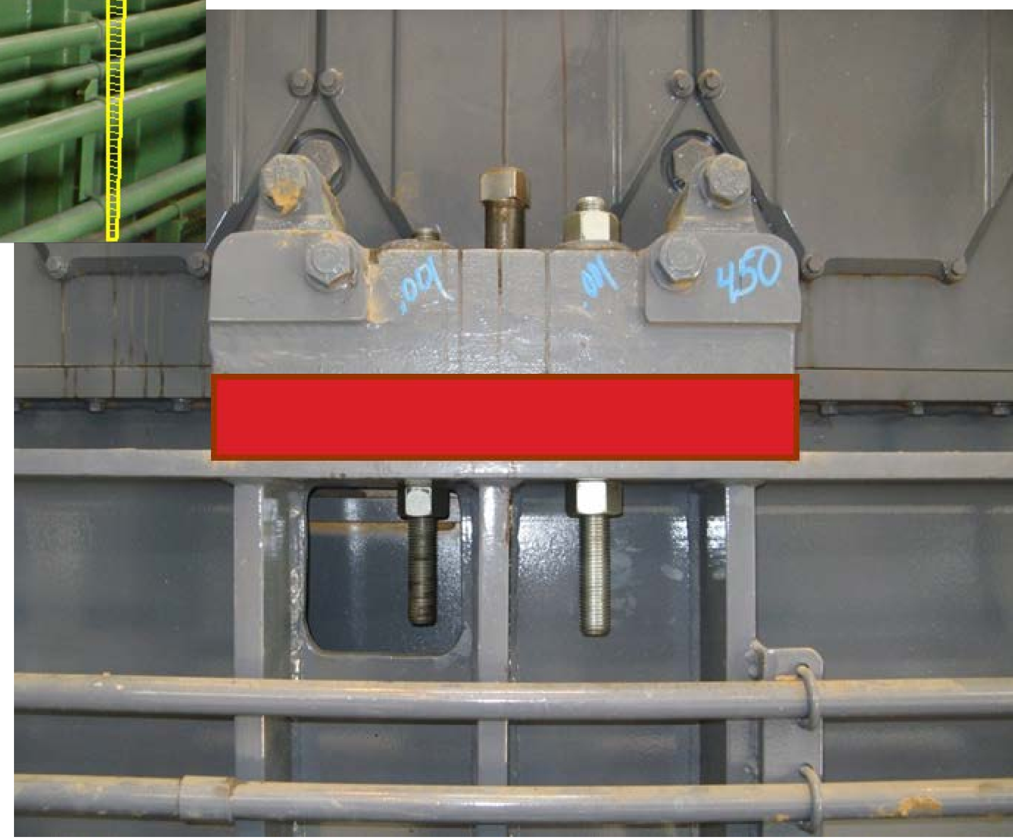
"These upgrades improve all operational aspects and capacities at Lake Dallas: from injection to withdrawal to wells to new automation to facilities," Jarzombek said. "A significant amount of the natural gas that we deliver in the winter is in the north Metroplex area. These upgrades are vital to supporting the gas supply needs of our customers, now and in the future."

End User Perspective
What Doesn't Work?

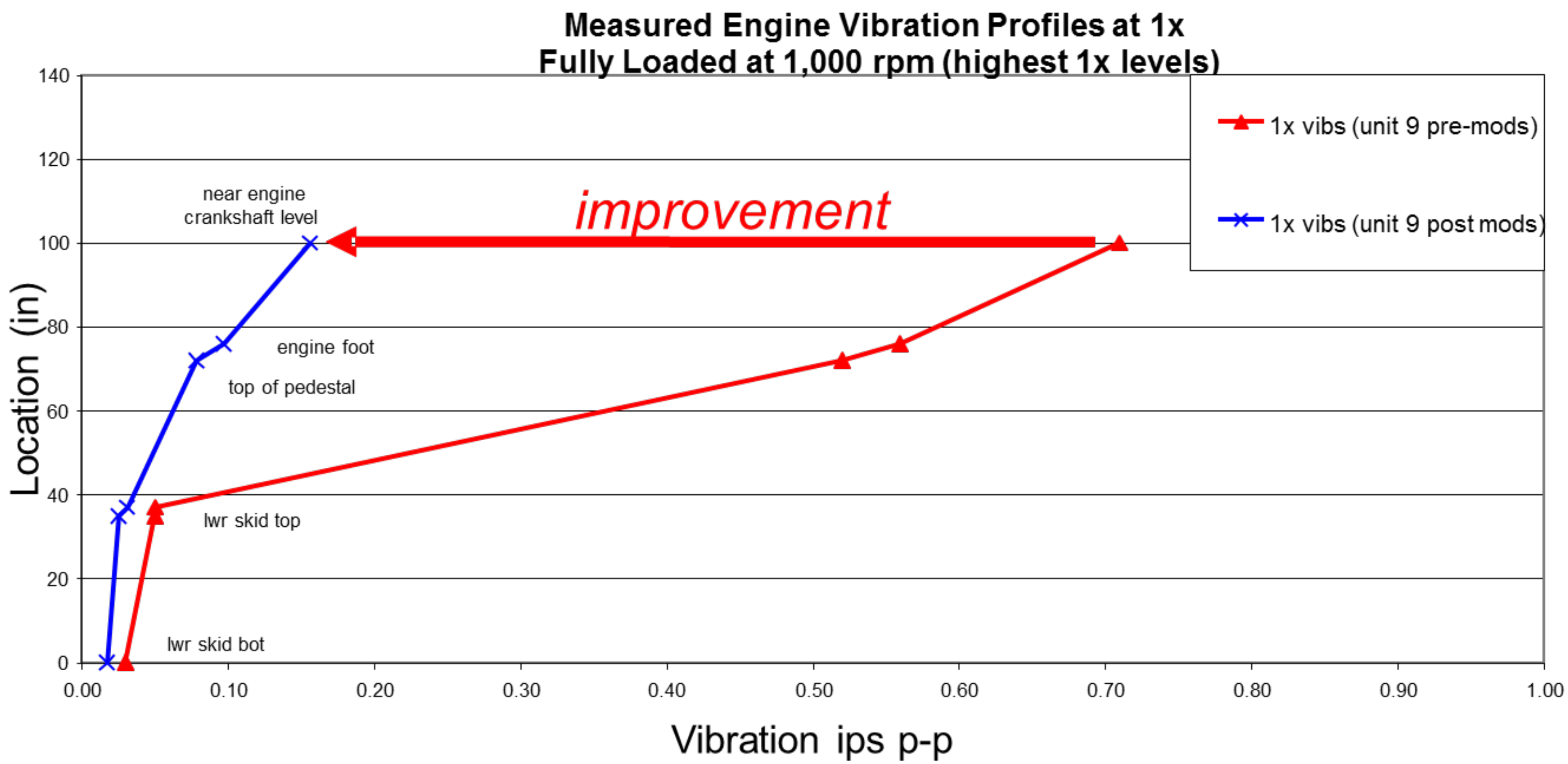


End User Perspective
What Doesn't Work?

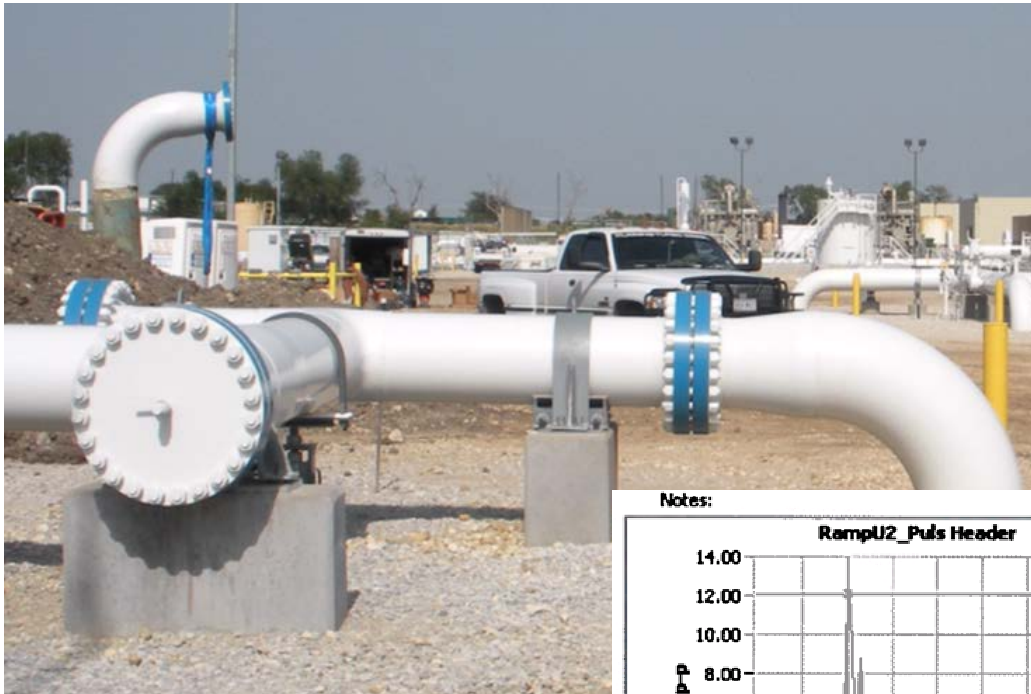


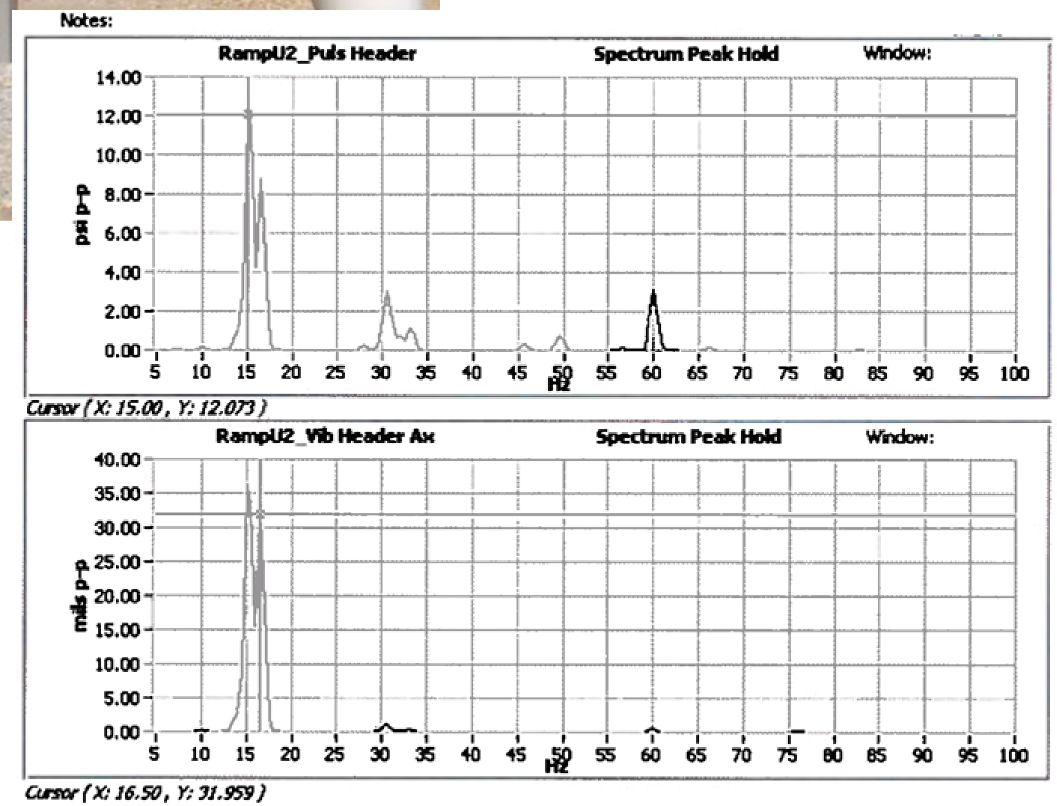


End User Perspective
What Doesn't Work?



End User Perspective
What Doesn't Work?





End User Perspective - Questions?

Compressor Considerations

Dave McCoy / Brandon Durbin, Ariel Corporation

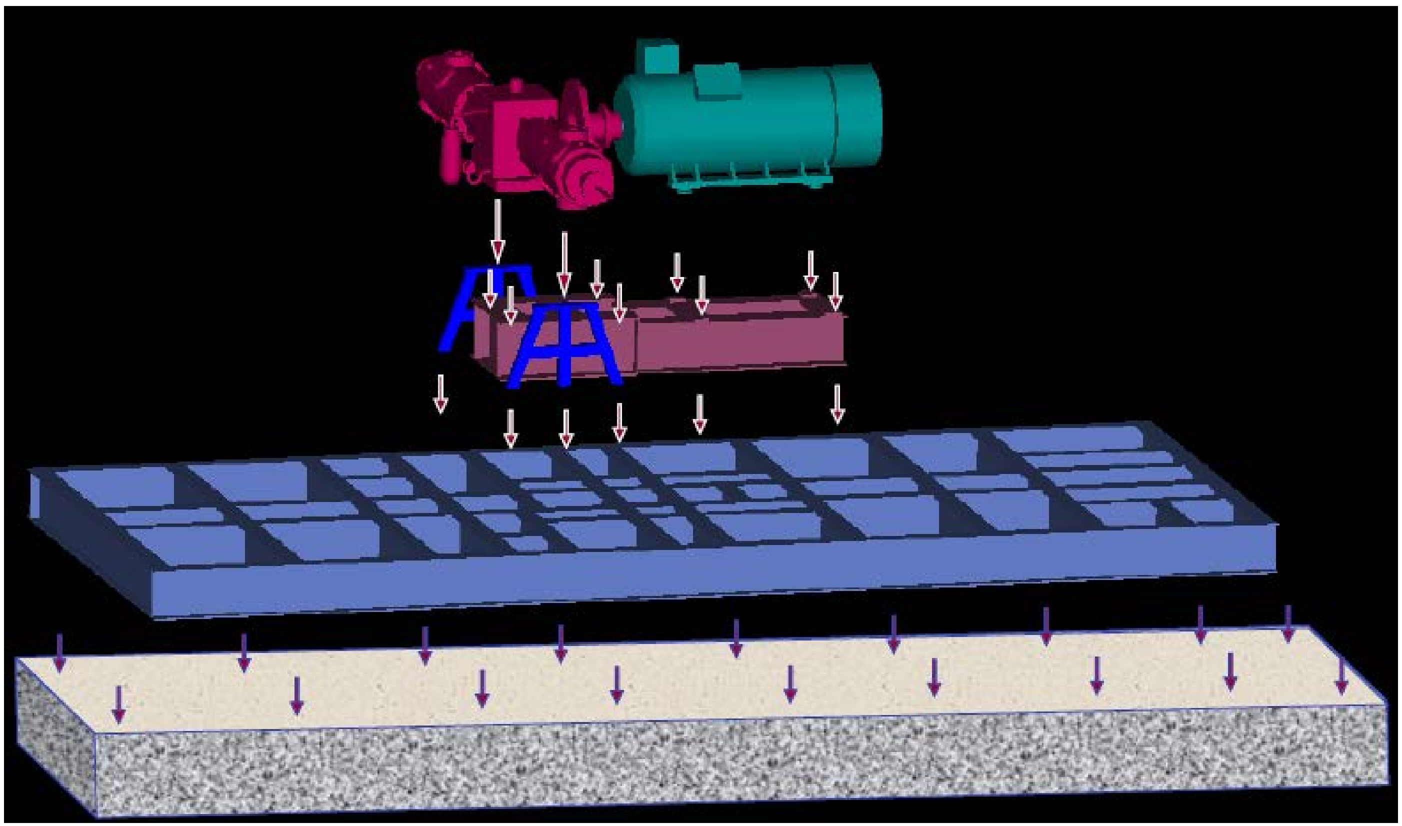
- Compressor Mounting & Equipment Installation
- Compressor Drain & Vent System Best Practices

Compressor Considerations
Compressor Mounting & Equipment Installation
Ref. Sections 6, 7, 10, 11 & 13

1. Foundation/inertia block design and construction
2. Block or inertia block mounting
3. Fabricated skid design
4. Setting major equipment
5. Compressor frame leveling
6. Pre-grout driver to compressor alignment
7. Grouting compressor frame and engine rails/skid to foundation
8. Hold down bolting torque and post grout leveling
9. Guide cylinder re-installation/ guide pre-load
10. Post assembly level check
11. Installation of interconnecting piping and instrumentation/ maintenance access
12. Commissioning checklist

The mounting system on a reciprocating gas compressor must:

- Position and support the compressor, driver and related equipment.
- Effectively transmit the vibration produced by dynamic forces down through the foundation while reducing or eliminating the harmful effects of those vibrations. The compressor and its foundation must form a tightly integrated structure. Vibration energy travels down and out through the foundation where the soil can absorb it.



Compressor Considerations
Foundation/Inertia Block Design & Construction
Section 6: Skid & Foundation

Engineering companies need to work directly with the local geotechnical companies to identify the soil conditions at the proposed site. An analysis should include the assessment of the foundation's natural frequency, damping, resonance, and the impact on vibration and dynamic stress.

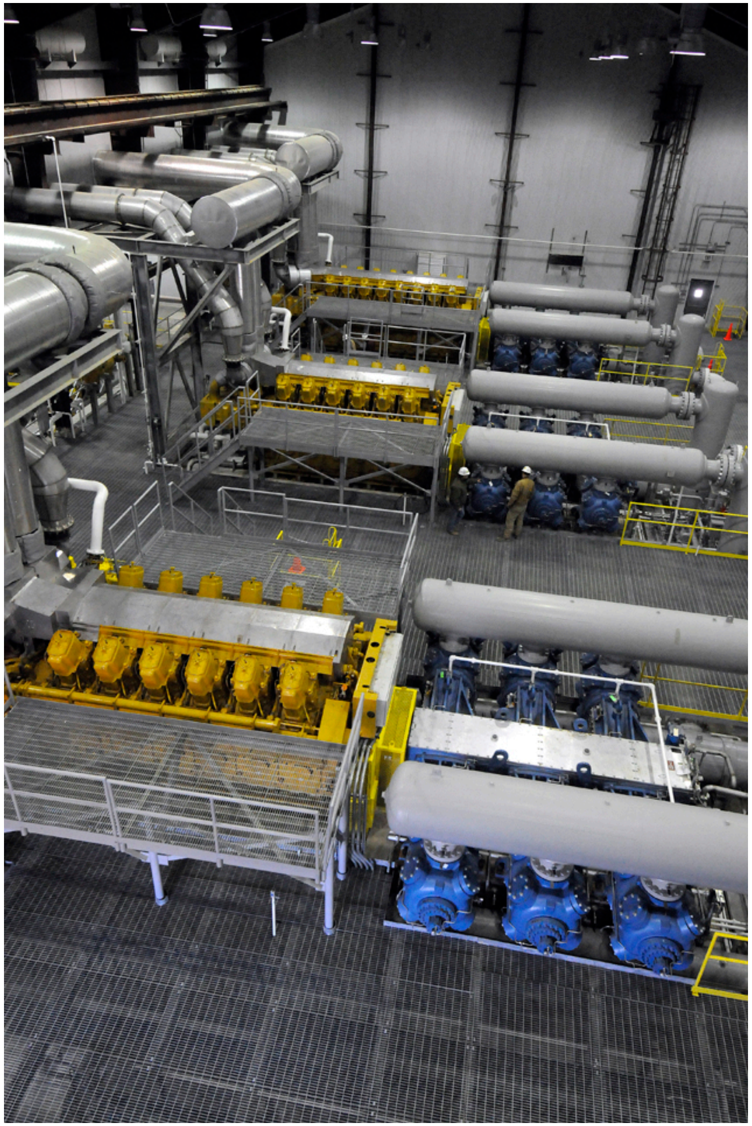
Civil Engineering evaluation of the following is required, regardless of the installation method.

- Subsoil
- Concrete mat or pad
- Concrete inertial block if req'd
- Anchor bolts
- Sole plates/chocks
- Grout

Compressor Considerations
Block Mounted Equipment
Section 6: Skid & Foundation

As horsepower and power density increase, consideration should be given to block mounting major equipment. This method is more capital intensive and requires significant on-site fabrication and assembly, but has proven over the years to provide the desired attributes of a successful installation.

Compressor Considerations
Section 6: Skid & Foundation



A well engineered block mounted installation can provide a very clean environment with emphasis on maintenance access.

Compressor Considerations
Skid Design
Section 6: Skid & Foundation

- The skid must have sufficient stiffness between the driver and compressor so that the torque reaction between them does not cause twisting.
- The skid must have also have enough stiffness and mass to limit skid deflection induced by the unbalanced forces and couples

- The skid will be designed with enough stiffness and strength so the compressor can be mounted flat with no bending or twisting of the compressor frame, crosshead guides, or cylinder.
- Compressor hold down bolting should be in accordance with manufacturers specifications
- The feet on the crosshead guides must be supported in a fashion that not only provides vertical support, but also prevents horizontal movement perpendicular to the piston rod.

Compressor Considerations
Foundation/Inertia Block Design & Construction
Section 6: Skid & Foundation

- API 618 DA3 does not include dynamic analysis of the skid and/or foundation design.
- The dynamic stiffness of the compressor package is critical if a skid mount design is chosen.
- A separate skid design and study is required for all off-shore and pile mounted skids.

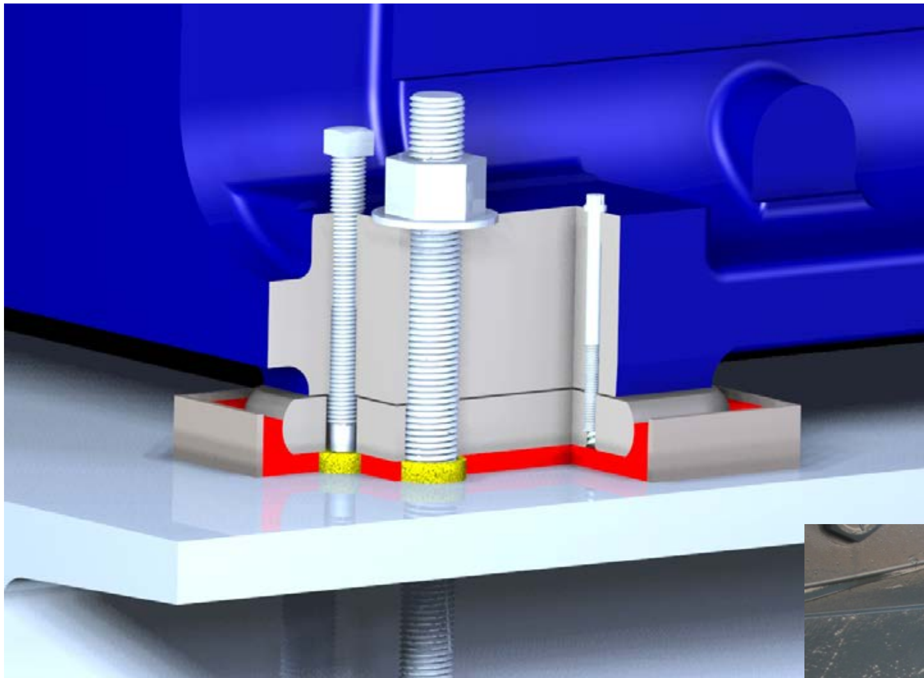
Compressor Considerations
Skid Mounted Equipment
Section 6: Skid & Foundation

Fabricated skid mounted equipment has also shown demonstrated success in many applications including 8,500 horsepower reciprocating compression.

Compressor Considerations
Setting Major Equipment
Section 13: Installation & Commissioning

The equipment interface with the fabricated steel skid or inertia block is a critical interface. Regardless of how solid the skid design or foundation, if the connection of the equipment to the skid isn't correct, issues will arise.

Compressor Considerations
Setting Major Equipment
Section 13: Installation & Commissioning



Methods to mount the frame to the skid include:

- Grouted sole plates
- Grout chocks
- Careful rail or full bed grouting

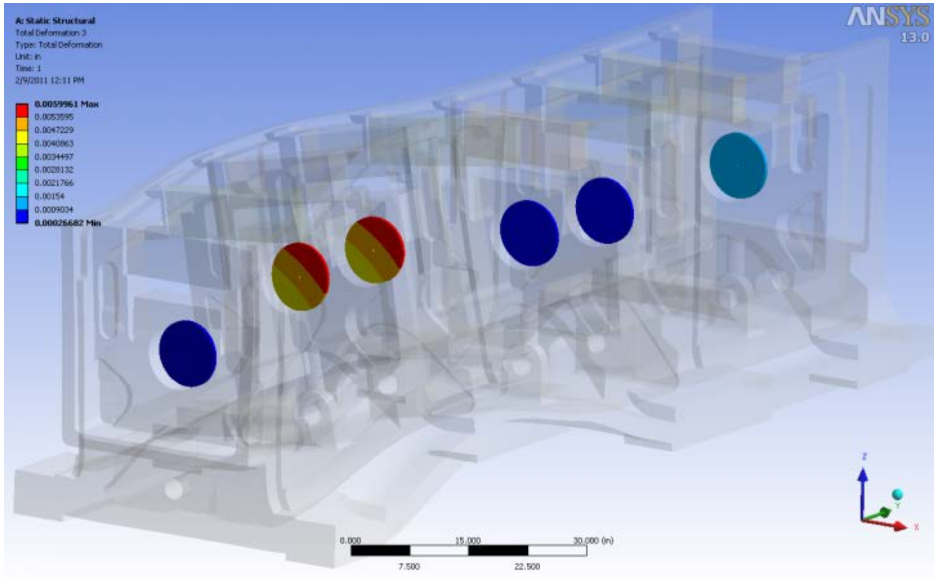
- When installing equipment to the skid or block, ensure all mounting points are flat and parallel to compressor feet to avoid angular and parallel soft foot.
- The mounting method depends heavily on packager's ability to duplicate skid flatness at installation.

Compressor Considerations
Setting Major Equipment
Section 13: Installation & Commissioning

Well-designed crosshead guide supports provide high axial (parallel to the crankshaft) and vertical stiffness that usually eliminates the need for head end cylinder supports (HES).

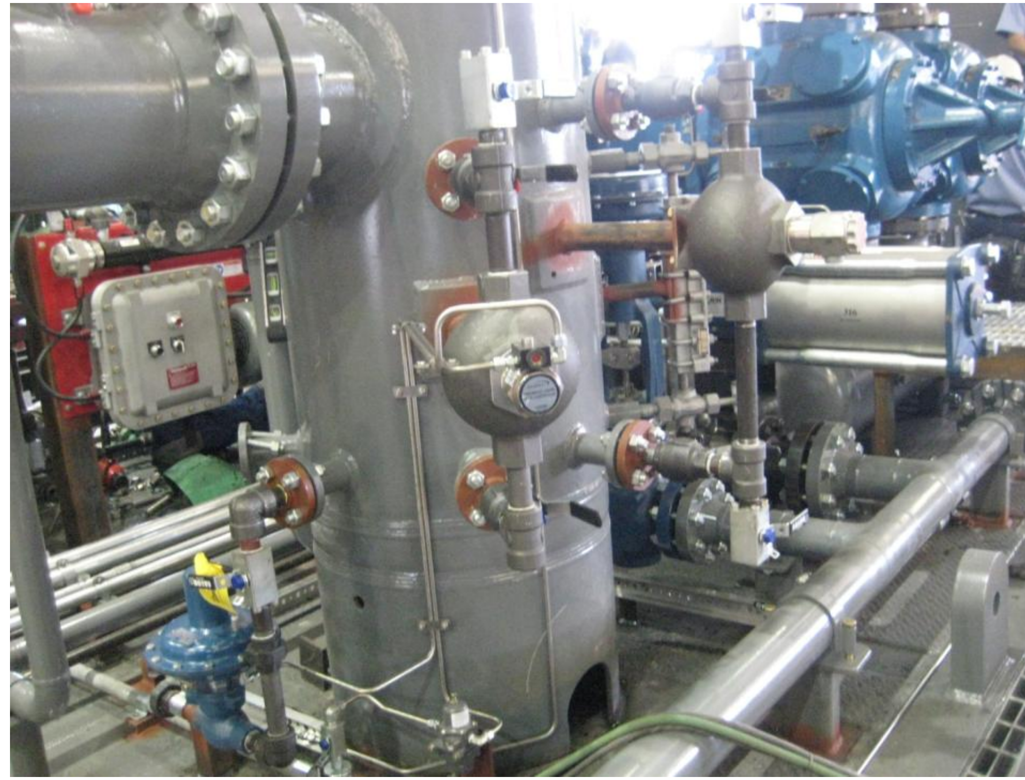
Welded steel chocks NOTE:
Flatness and parallelism can be difficult to achieve using this method. It is recommended to machine steel chocks after welding to avoid angular soft foot, which requires the use of step shims or re-machining in the field. Step shims create point loading and will not provide adequate contact between the foot and chock.

Compressor Considerations
Compressor Frame Leveling
Section 13: Installation & Commissioning



Equipment manufacturers specify level/flatness criteria for various compressor frame classes. Some include crankshaft web deflection checks; others require frame flatness measurements and soft foot checks. The best practice will ensure that the compressor main bearing bores are in alignment as machined by the OEM.

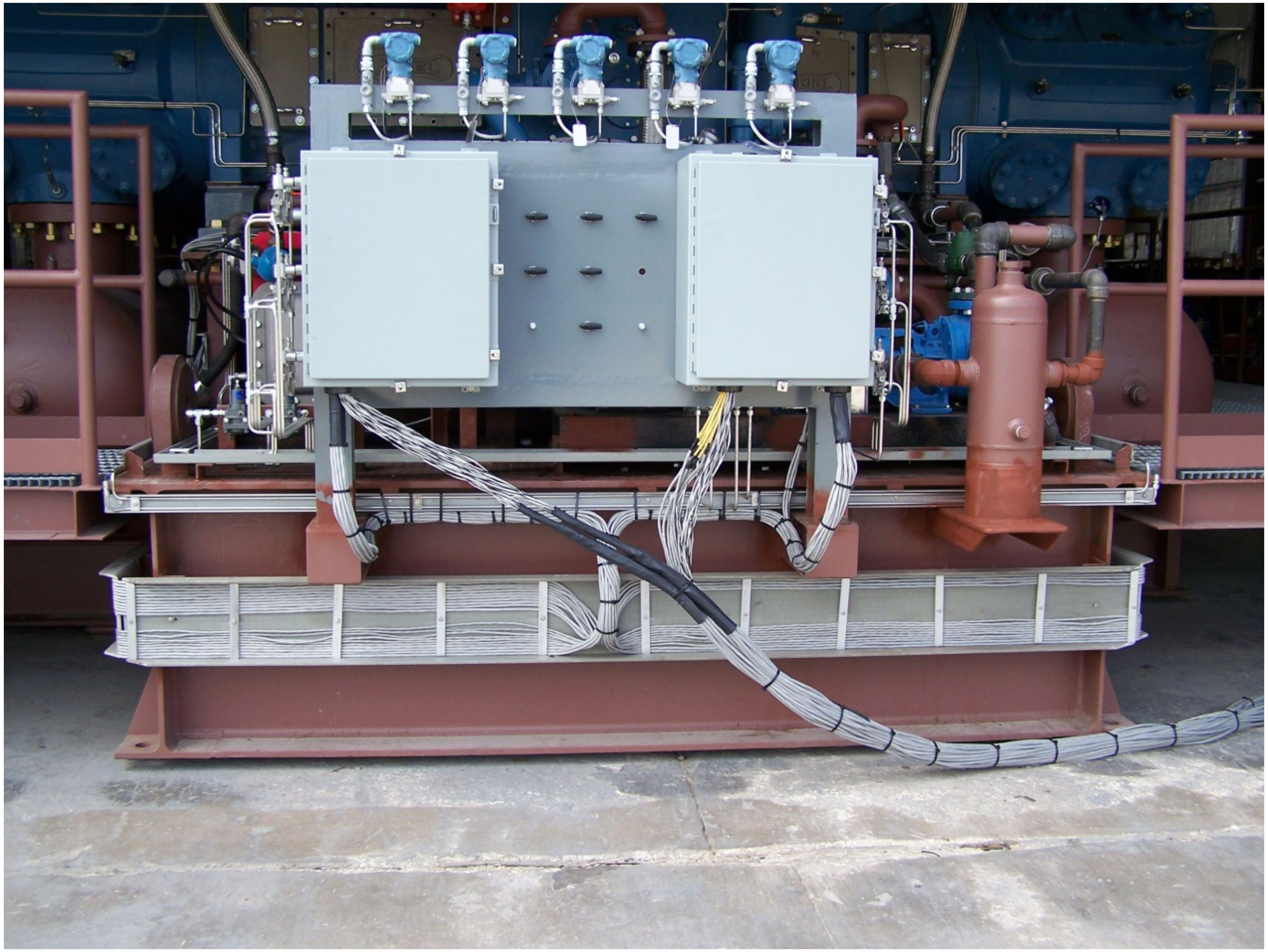
Compressor Considerations
Compressor Frame Leveling
Section 7: Vibration Control



As discussed earlier, small bore piping and instrumentation tend to manifest the ill effects of vibration. Small bore attachments require careful consideration.

Compressor Considerations
Compressor Frame Leveling
Section 10: Maintenance Access

Compressor Considerations
Compressor Frame Leveling
Section 11: Instrumentation



The use of armored ship board cable virtually eliminates nuisance shutdowns caused by chaffing wires and water or liquids in conduit. It also makes for a very clean installation when placed in cable trays.

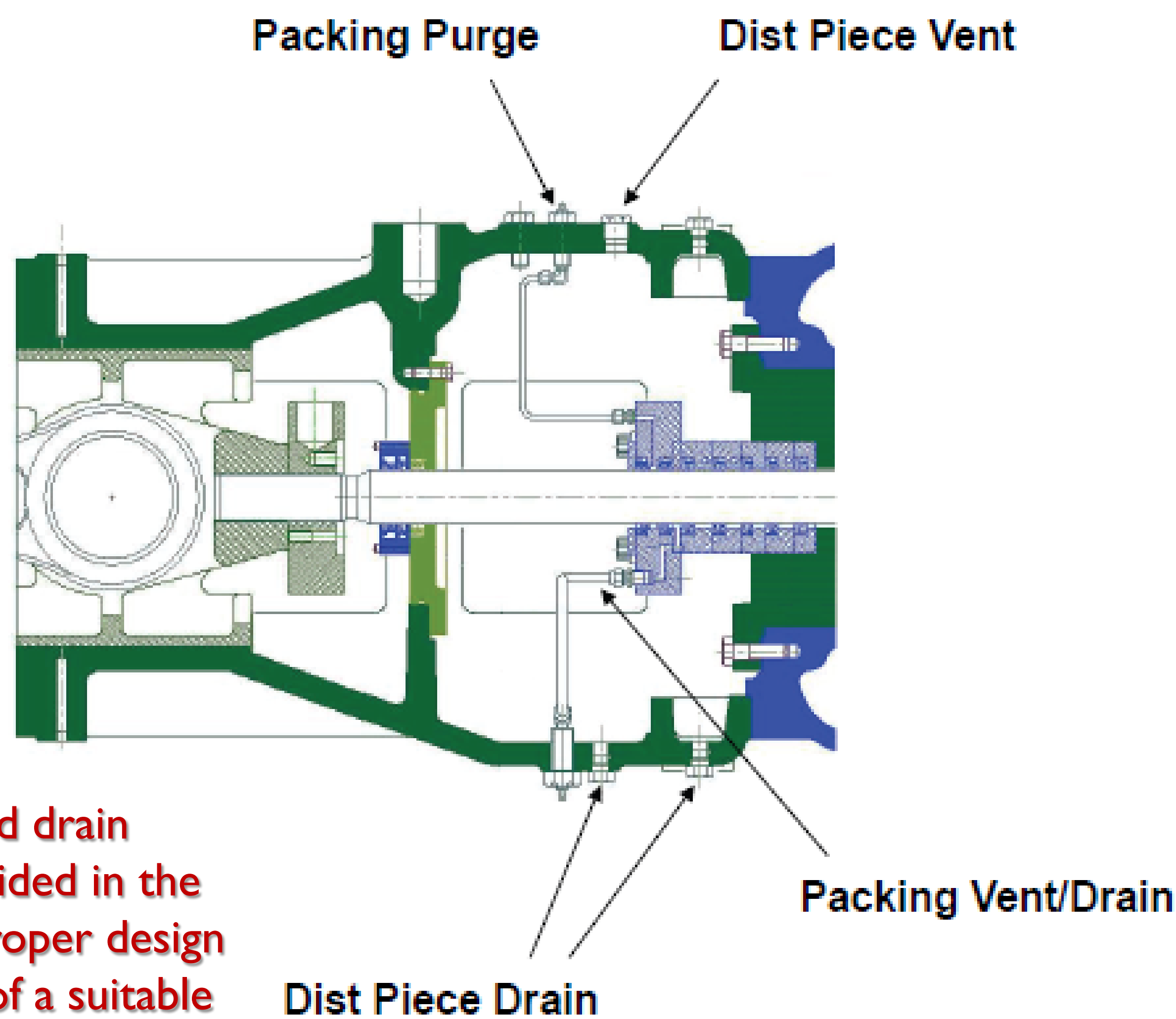
There are of course some local customs or practices that aren't anticipated but should be observed.

OEM commissioning documents and recommended practices must be used to insure all system and mechanical checks are conducted and documented. There can still be gaps in documentation of the individual components that must be accounted for prior to commissioning activities. Again, some of the earlier documented papers provide guidance for compiling documentation and planning the commissioning activities.

Distance Piece Connections

Compressor Considerations
Vent Gas Systems for Reciprocating Compressors
Section 9.13

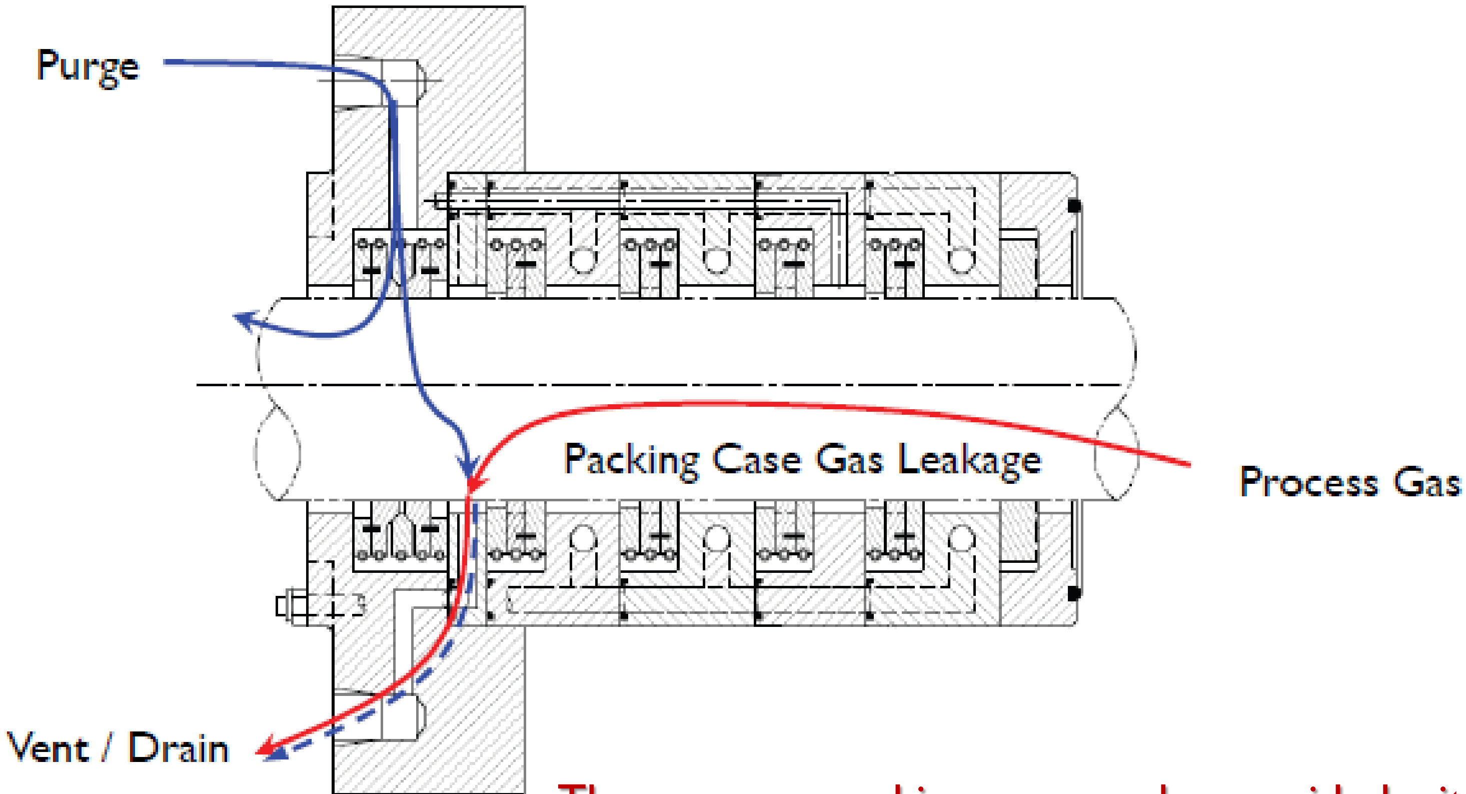
Long, Single Compartment Distance Piece



All necessary vent and drain connections are provided in the distance pieces for proper design and implementation of a suitable purge and vent system.

Compressor Considerations
Vent Gas Systems for Reciprocating Compressors
Section 9.13

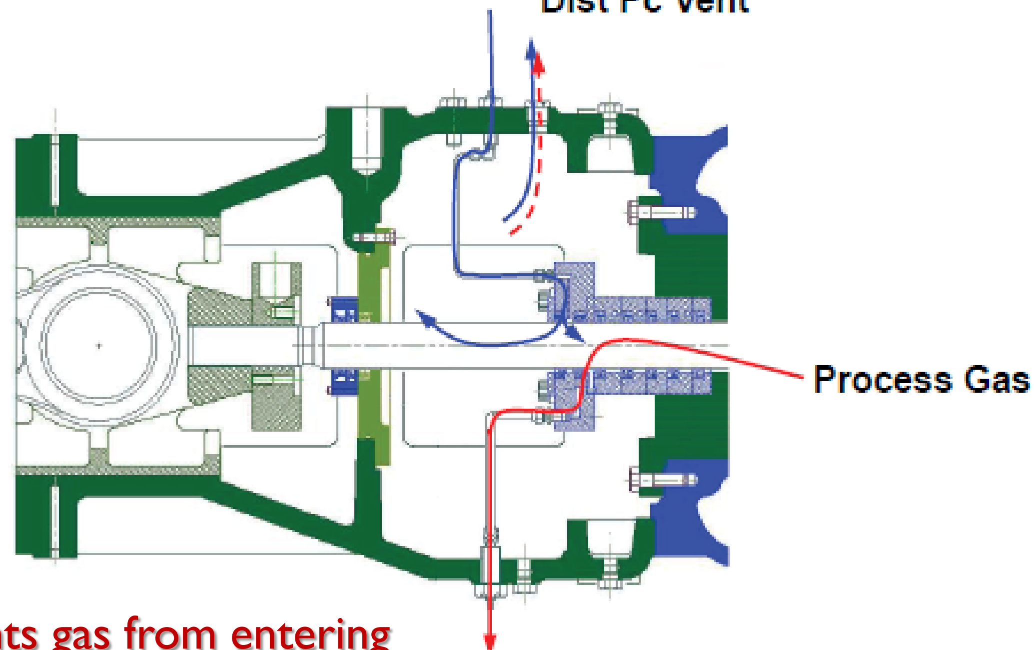
Purged Packing



The pressure packing case can be provided with a purge seal ring set to help route the leakage gas through the packing case vent, rather than into the distance piece.

Long, Single Compartment Distance Piece

- Higher Purge Gas Pressure Ensures Packing Gas Leakage is Routed Through the Packing Vent/Drain.

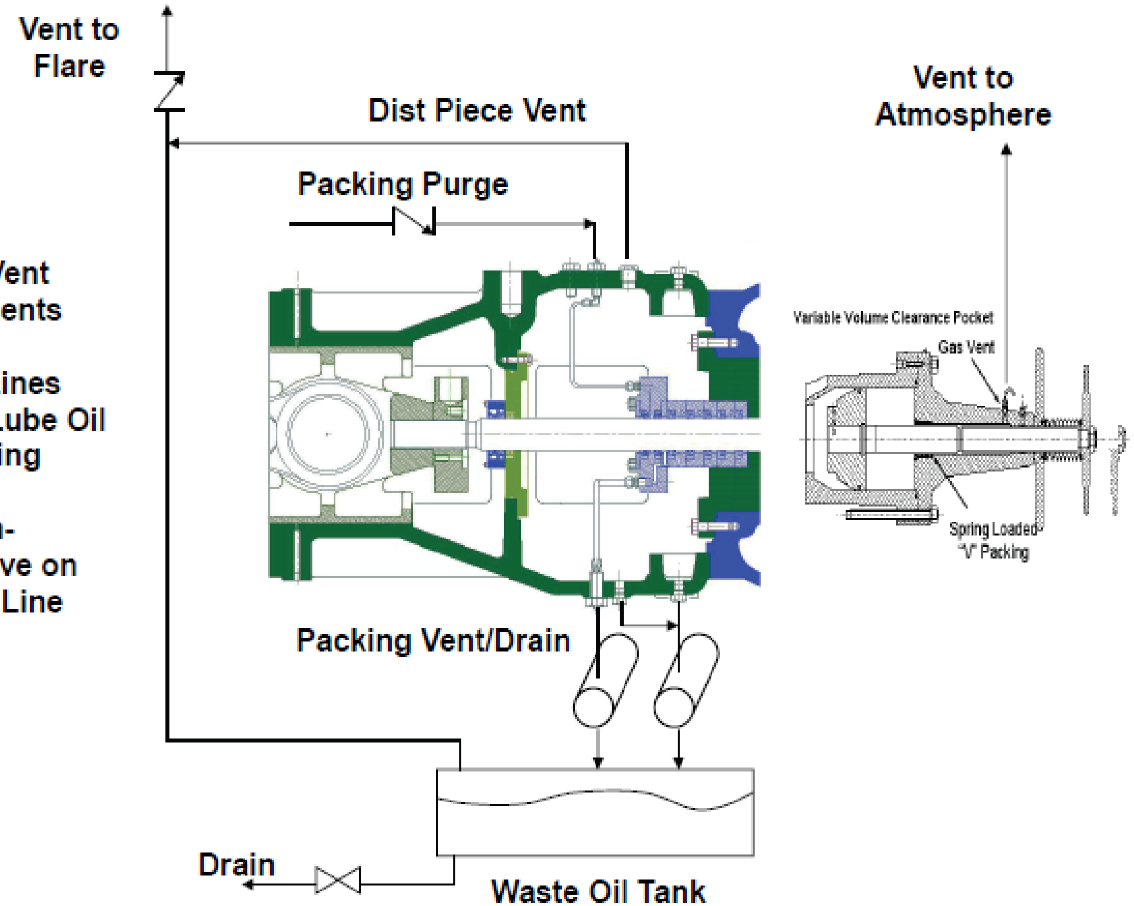


The packing case purge prevents gas from entering the distance piece. However, as the packing rings wear, and the packing case vent flow increases, and the vent pressure can exceed the purge pressure, allowing gas to enter the distance piece. This requires that the distance piece vent be considered a primary vent.

Compressor Considerations
Vent Gas Systems for Reciprocating Compressors
Section 9.13

Venting to Flare

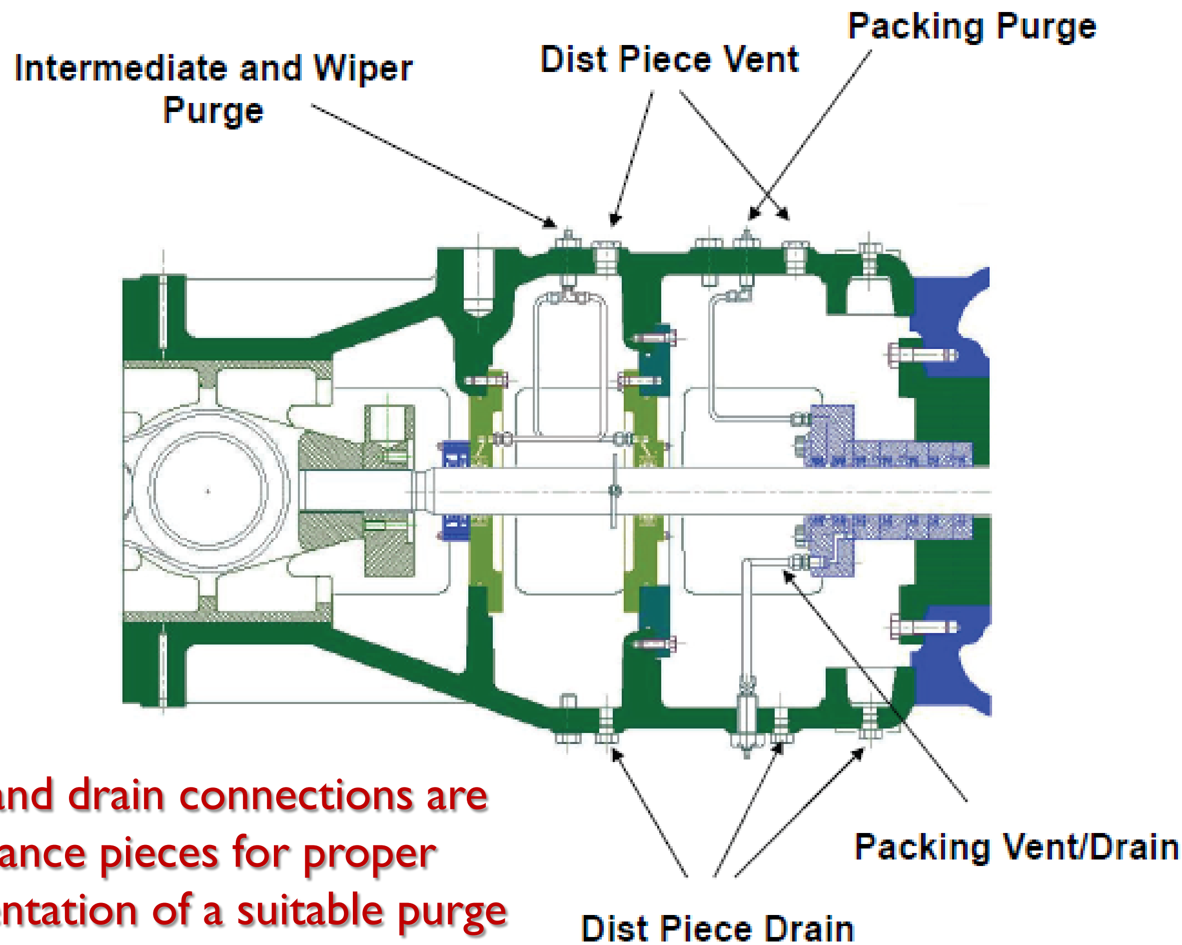
- Separate Vent Compartments
- Maximize Manifold Lines
- Separate Lube Oil from Packing Vent Gas
- Install Non-Return Valve on Final Vent Line



Venting to the Atmosphere has been common with non-toxic or non-lethal gasses. However, venting to atmosphere is not acceptable for toxic or lethal gasses and becoming unacceptable for natural gas due to future EPA regulations on GHG's. Additional governmental regulations may be restricting venting to the atmosphere.

Compressor Considerations
Vent Gas Systems for Reciprocating Compressors
Section 9.13

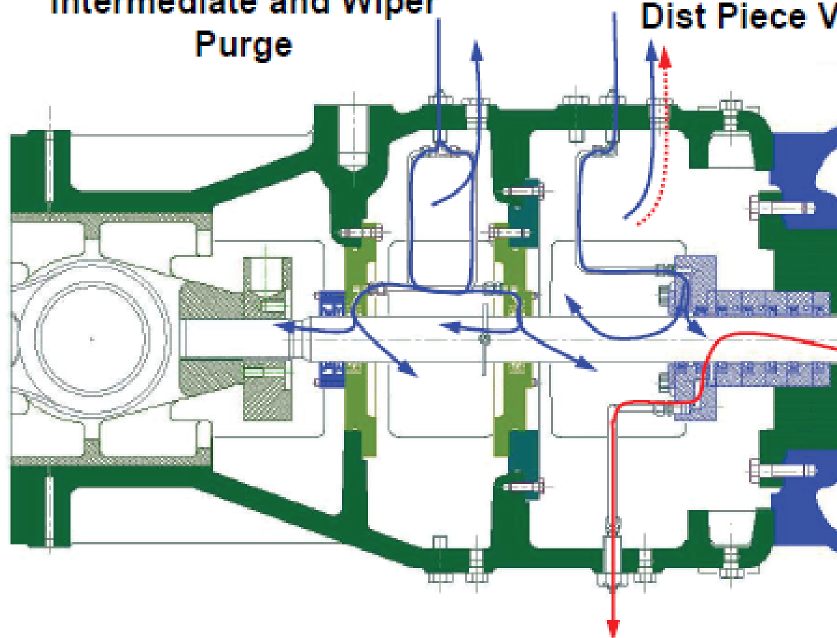
Long, Two Compartment Distance Piece



All necessary vent and drain connections are provided in the distance pieces for proper design and implementation of a suitable purge and vent system.

Long, Two Compartment Distance Piece

- The Long Two Compartment Distance Piece Offers Greater Protection



The long two compartment distance piece can have the capability of purge seal sets at three seal set locations, adding further protection.

Compressor Considerations
Vent Gas Systems for Reciprocating Compressors
Section 9.13

Long, Two Compartment Distance Piece

- Separate Vent Compartments
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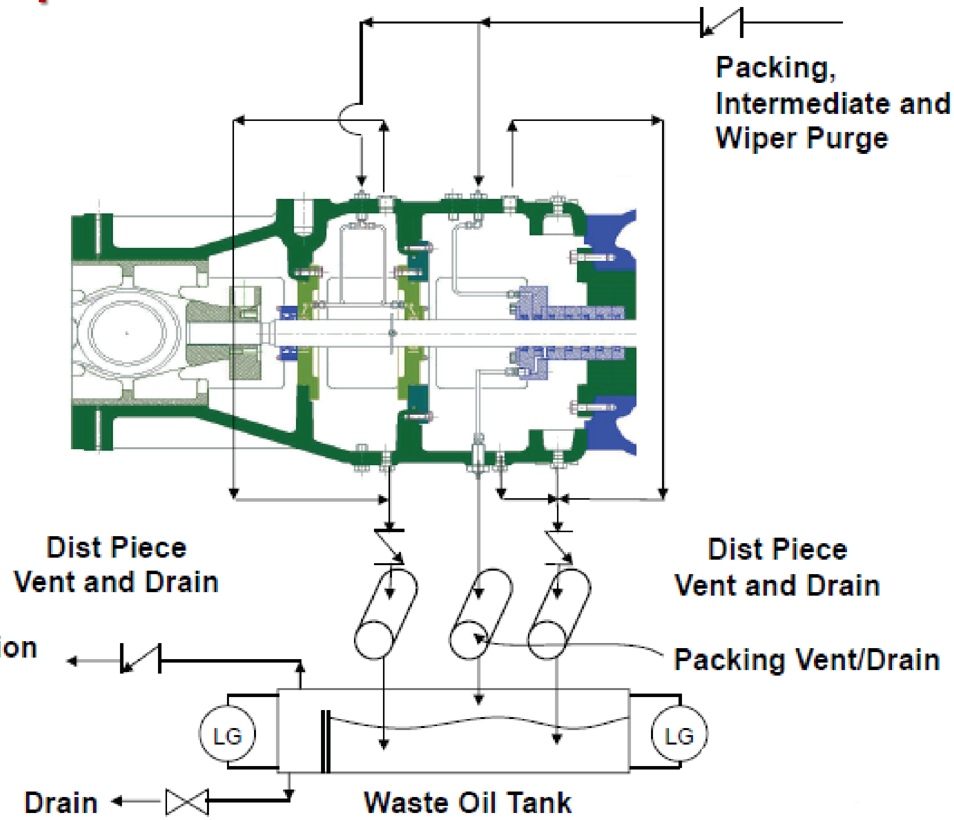
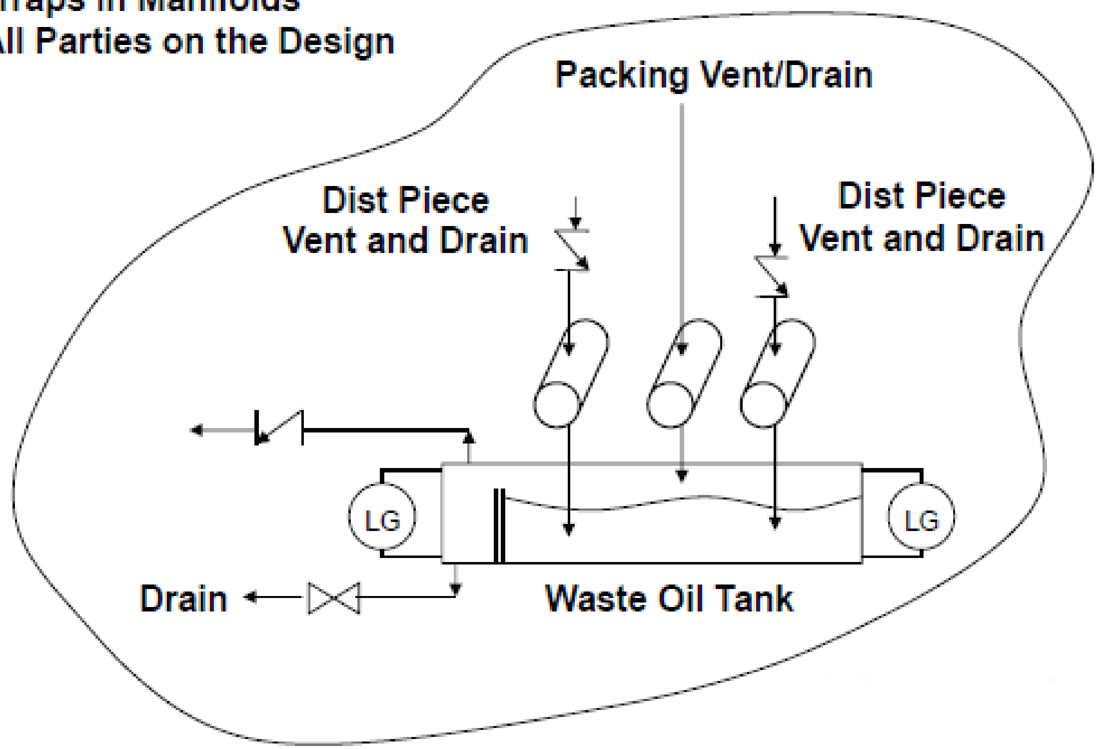


There are 3 vents, and often only one disposal location for the vent gas. The 3 vent connections must not be allowed to transfer gas from one vented compartment to the other vented compartment. But with one disposal location, they need to be tied together. Check valves can be used, but can foul up due to contaminants in the oil and gas mixture. A liquid check valve in the Seal Pot is a very effective means of tying these vents and drains together.

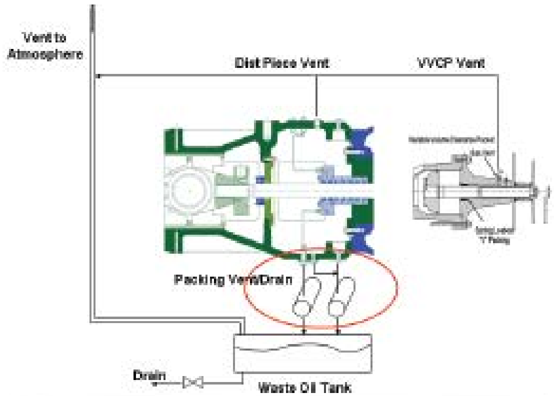
Waste Oil Tank

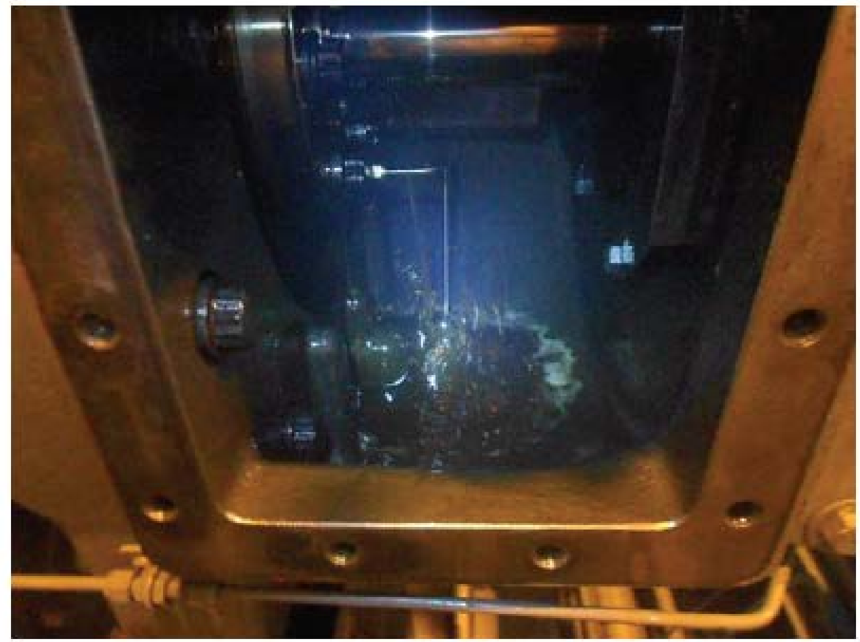
Waste Oil Tank Location: On Skid or Off Skid?

- Minimize Pressure Drop
- Slope Drain Manifolds
- Avoid Low Level Traps in Manifolds
- Coordinate with All Parties on the Design



Keeping Packing Vent Separate from Drains





If the packing vent / drain connection is tied to the distance piece drains prior to entering the oil separation pot, the packing vent flow can go back through the drain connections to vent through the top of the guides. This will not allow the oil to drain from the distance piece.

Expected Packing Leakage Rates

Purge gas provides the source for areas of higher pressure that help direct the process gas to the vents at lower pressure.

Purge gas pressure should be 5 to 15 psi higher than the vent pressure

Typical Purge Gas Usage: 5 to 10 SCFH per purge point.

Typical Packing Leakage Rates:

New: 5 to 10 SCFH per pressure packing case

Worn: Up to 100 SCFH per packing case

Compressor Considerations - Questions?

Engine Considerations

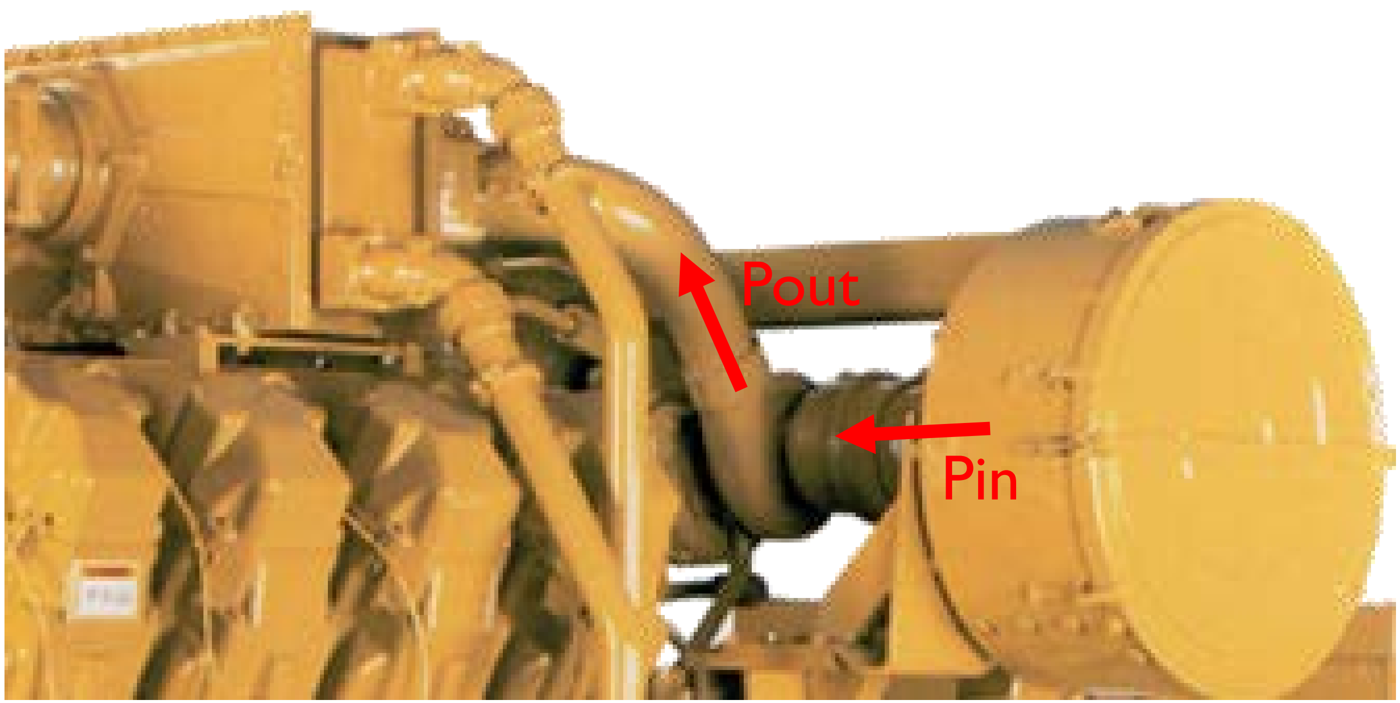
Ken Hall, Caterpillar

- Engine selection (fuel, site conditions)
- TVA validation of driveline
- Engine mounting and alignment
- Engine external connections
    - Cooling (JW & aux, venting)
    - Air intake / exhaust
    - Fuel
    - Lube
- New material in OEM spec

Engine Considerations
Site Impact on Engine Rating

Engine selection can be affected by site conditions in two ways:

- **Intake air density too low**
- Intake air cooling insufficient



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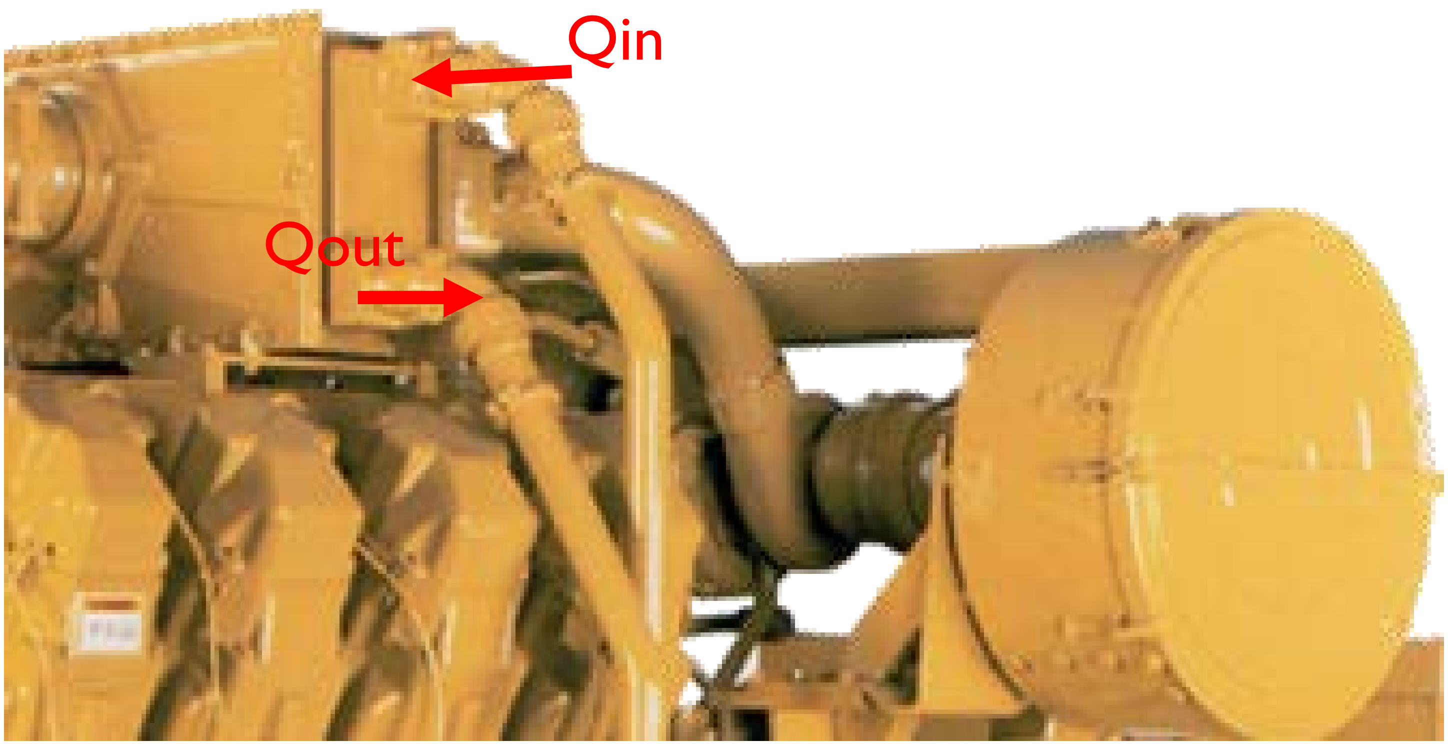
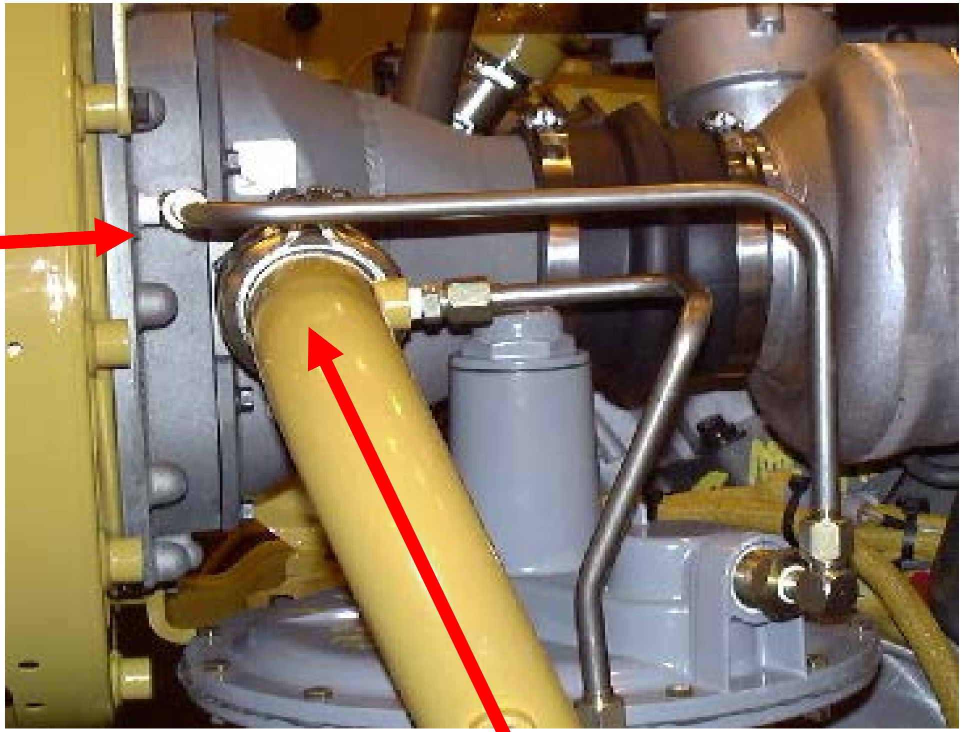


Engine Considerations
Fuel Impact on Engine Rating

Engine selection can be affected by fuel quality in several ways:

- **Fuel LHV out of range**
- Fuel MN out of range
- Fuel inert level too high
- Fuel contaminant level too high



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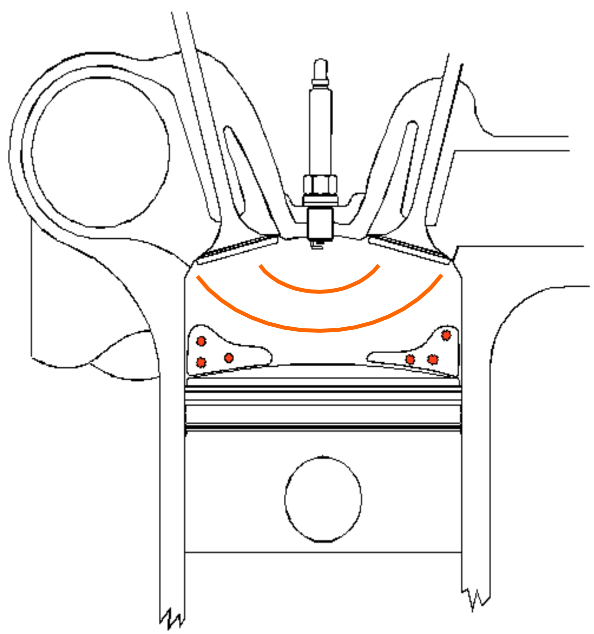
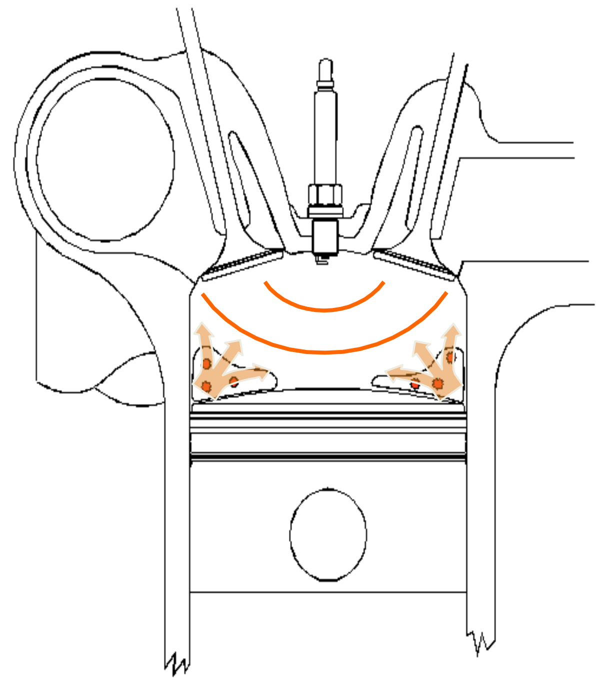


normal combustion



detonation

Engine Considerations
Fuel Impact on Engine Rating

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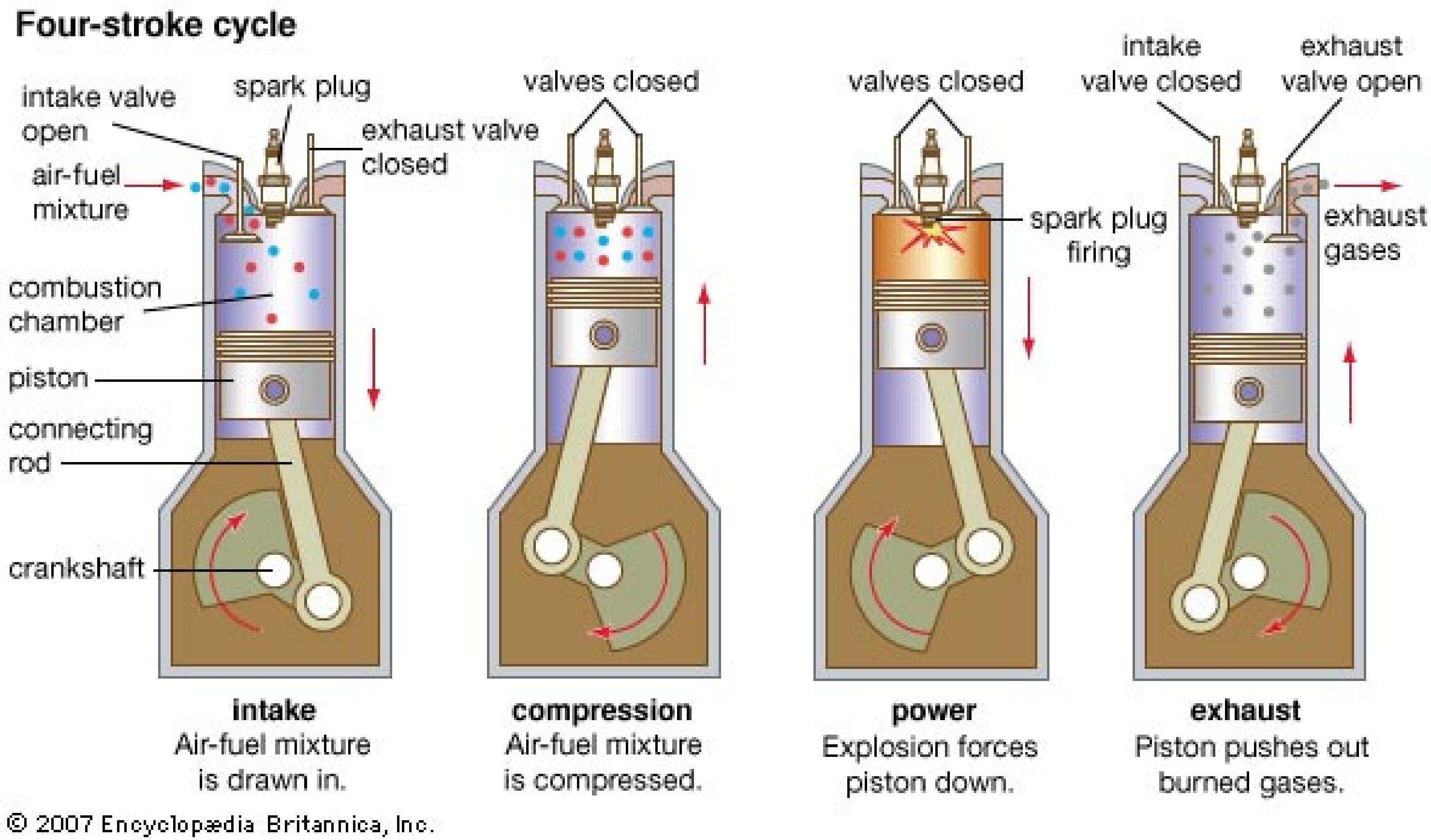


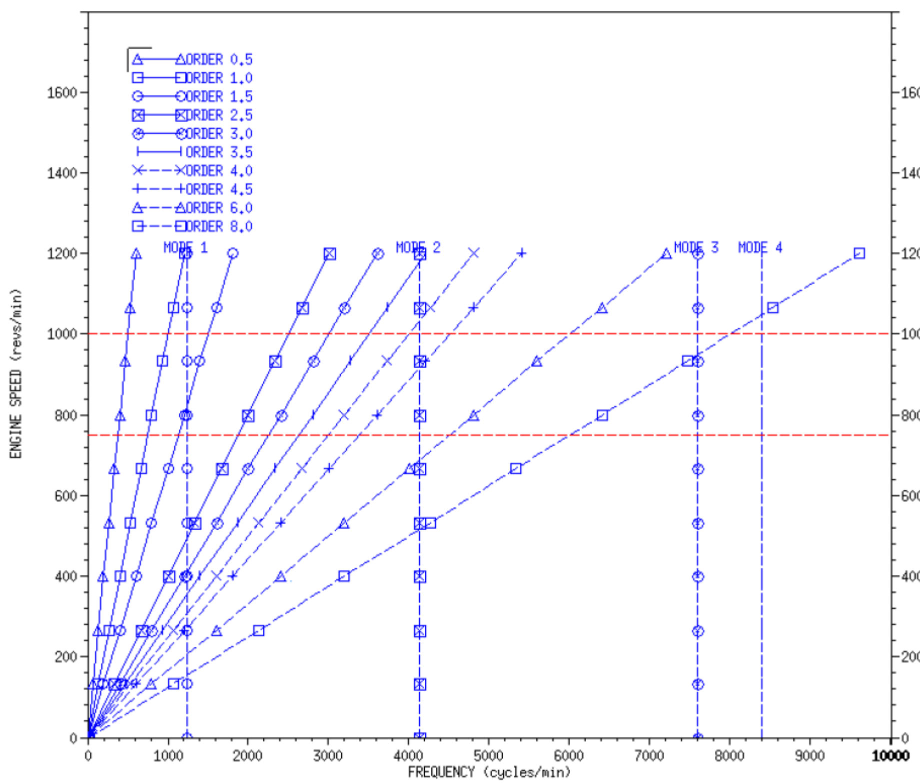
Engine selection can be affected by fuel quality in several ways:

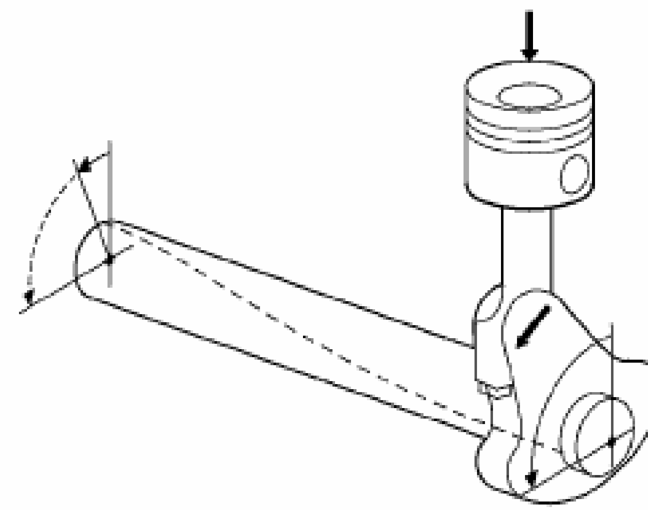
- Fuel LHV out of range
- Fuel MN out of range
- Fuel inert level too high
- **Fuel contaminant level too high**

Best Practices for Specifying & Procuring a Successful Large, Hi-Speed Reciprocating Compressor Package

A TVA is required to ensure proper selection of the engine damper, engine flywheel, and coupling based on the load-speed operating points for the compression package

Resonant Speed Diagram

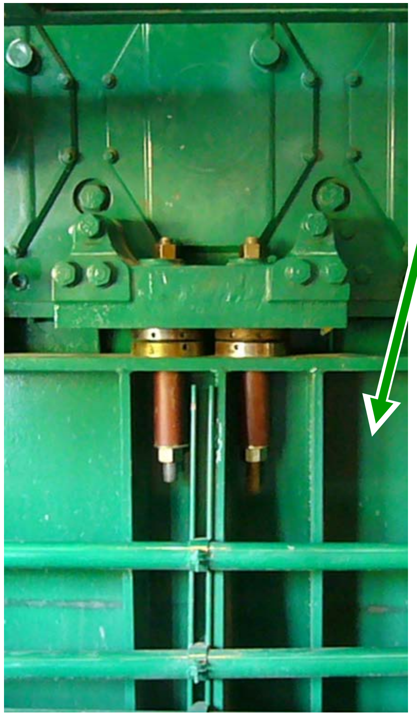


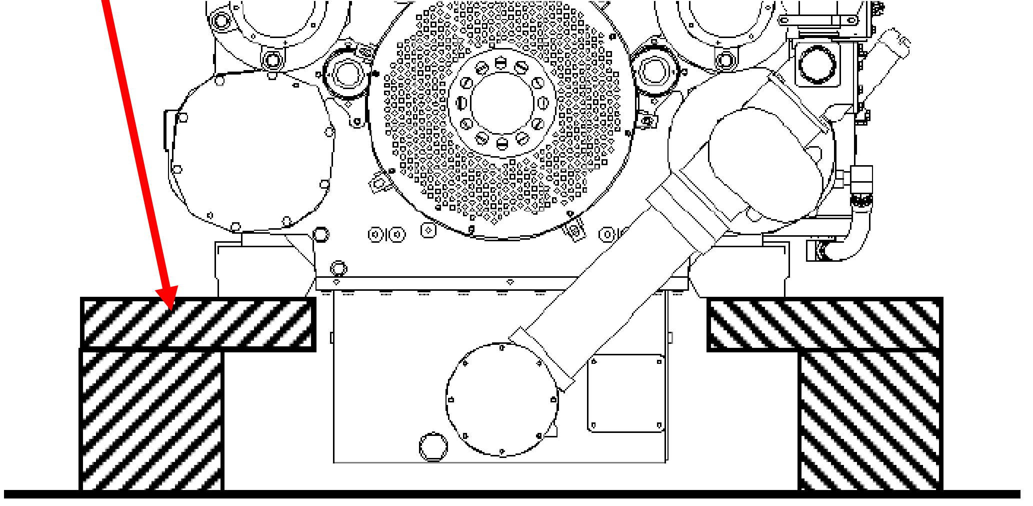


Engine mounts must be:

- **Designed to be robust**
- Installed/adjusted properly

Foundation beneath mounts should provide solid support. Cantilevered mountings are not recommended due to risk of excitation.





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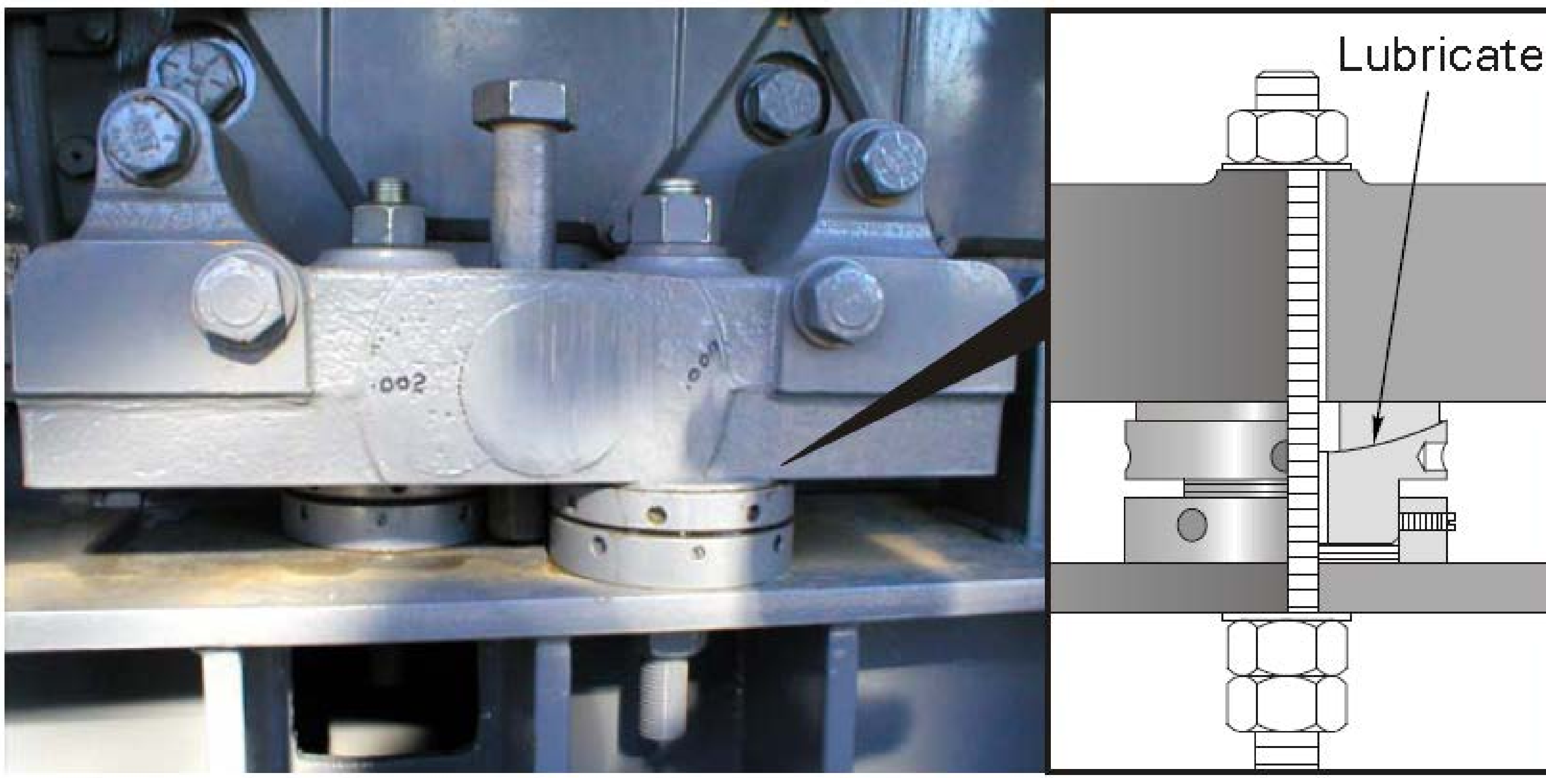
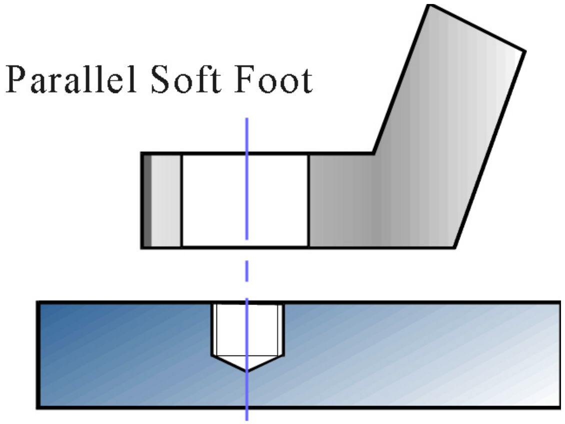
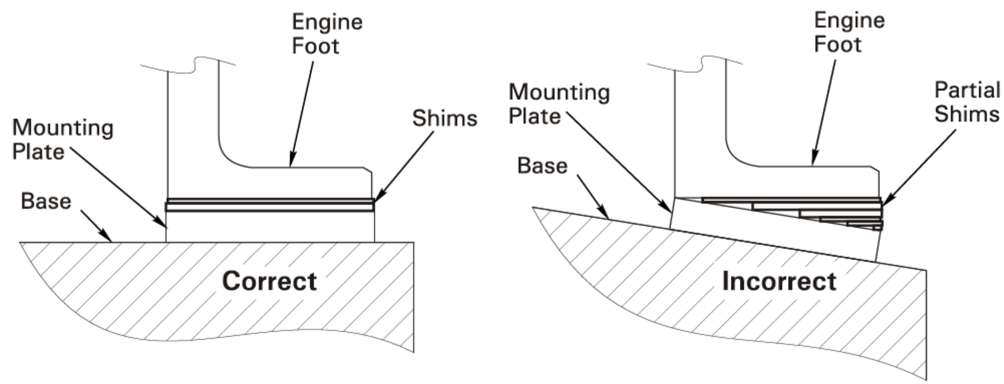
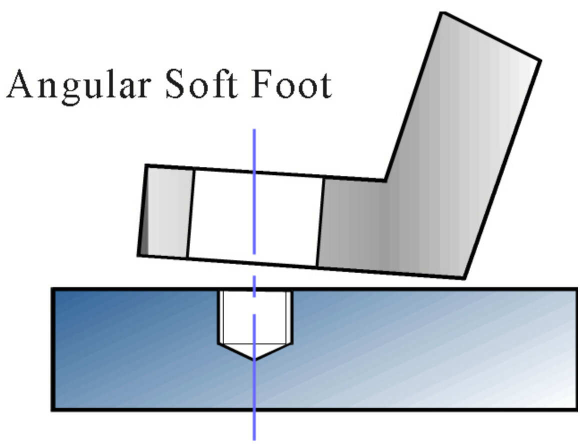
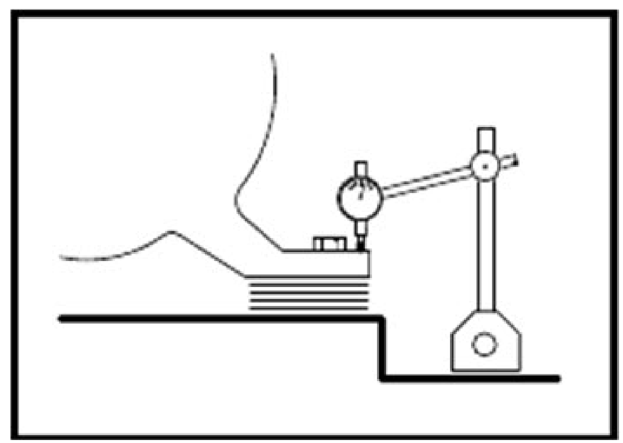


Properly implemented mounts provide a robust, stable support while eliminating gaps between the mounting foot and the foundation surface ("soft foot").



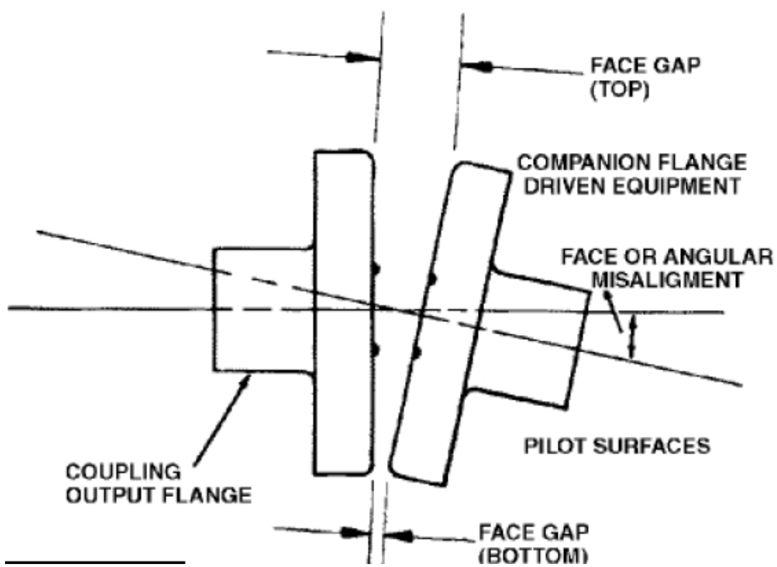




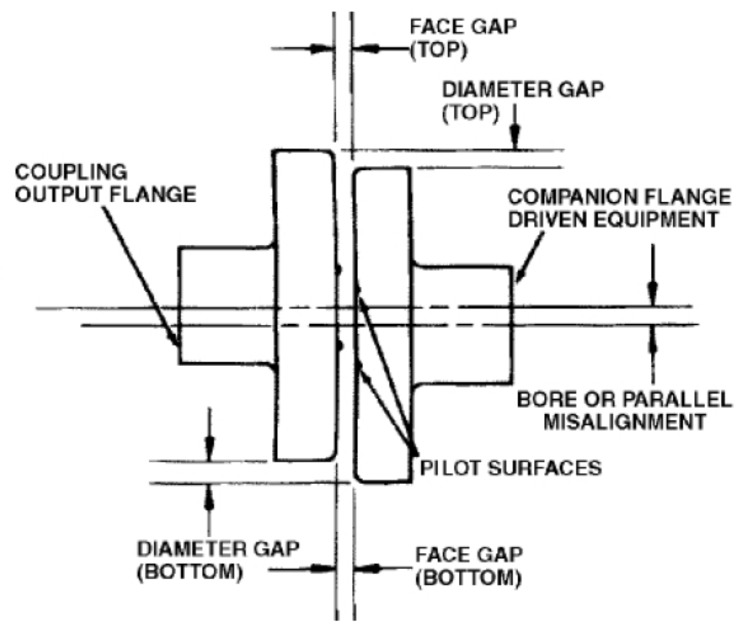


Engine alignment to driven equipment must be measured to eliminate angular and radial shaft offset that can lead to damage.

- Alignment should be verified before grouting the base.
- Engine should be prelubed before rotating crankshaft.



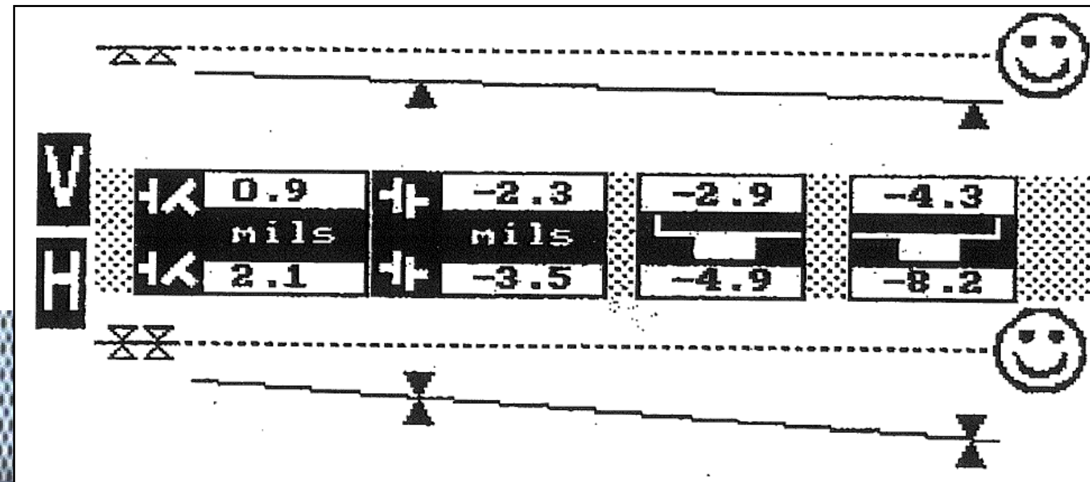
Angular Misalignment

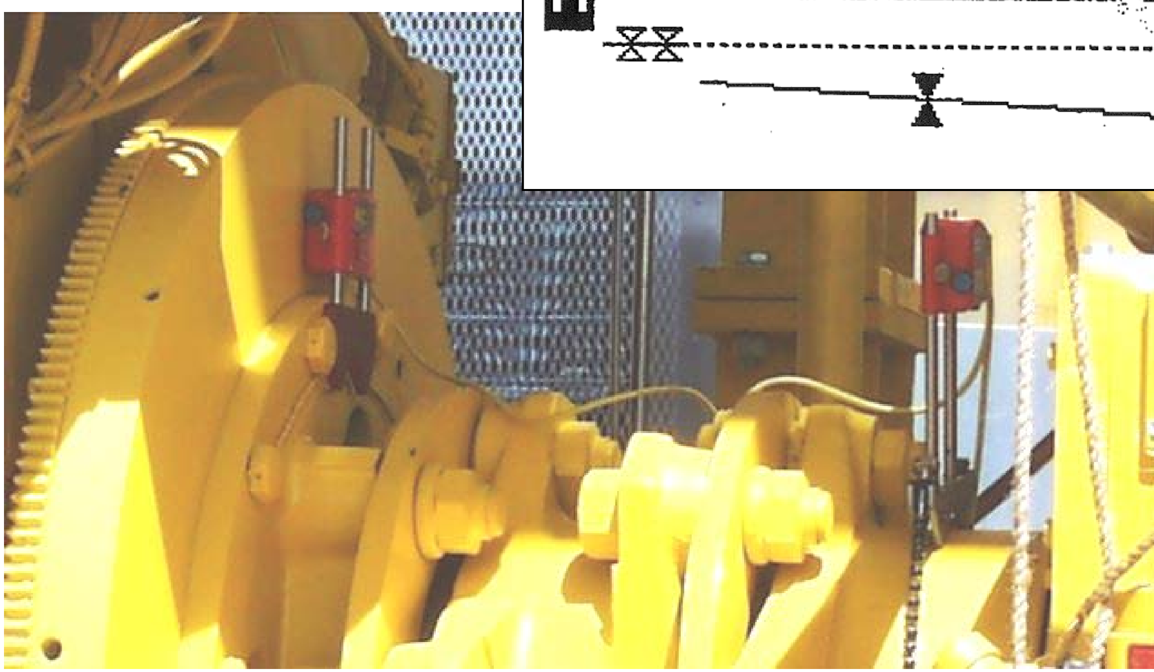


Radial Misalignment

Engine alignment to driven equipment must be verified:

- By cold check initially, to confirm alignment
- By hot check, to verify acceptable alignment at operating temperatures

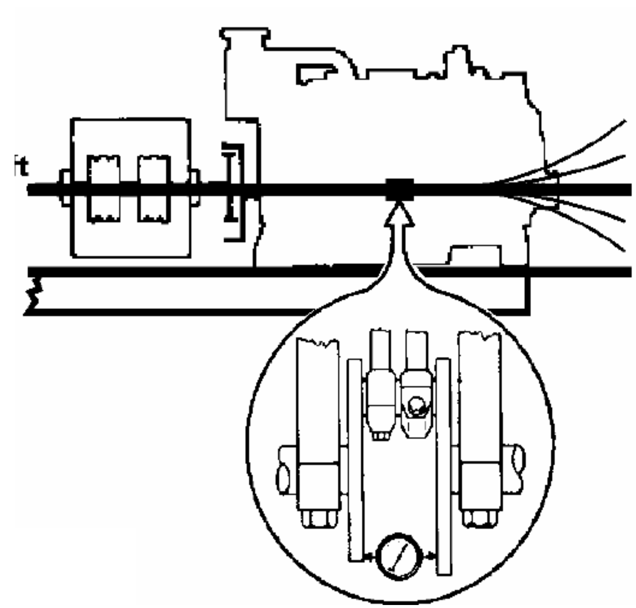




Engine Considerations
Engine Mounting / Alignment

Engine crankshaft end play

- Verify during soft foot check to keep from having to re-adjust engine location

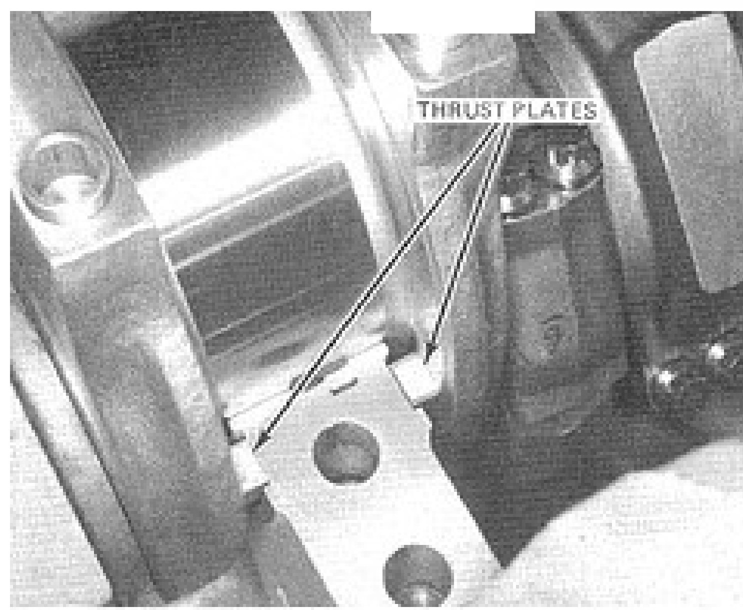


Crankshaft deflection check verifies:

- soft foot
- Alignment - must be checked hot

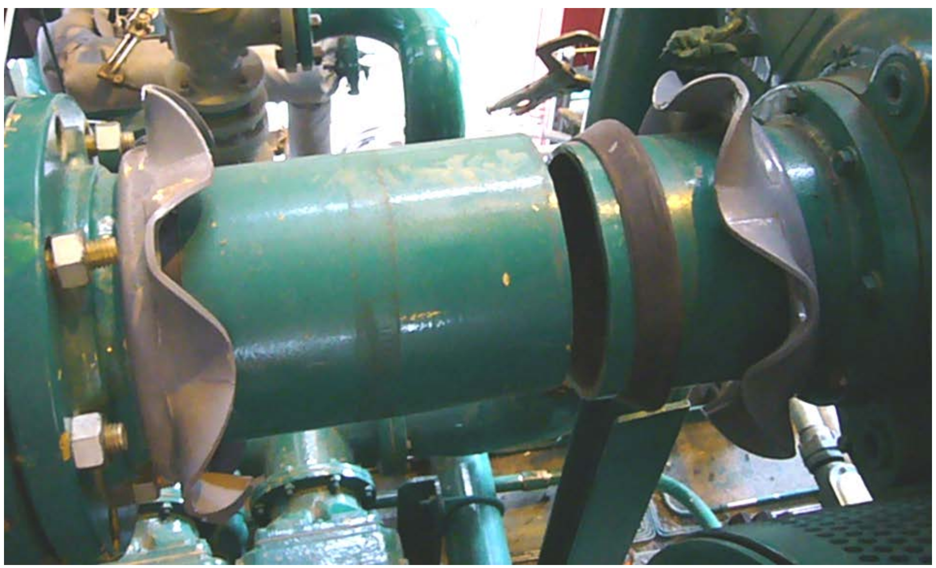
System connections
(example: cooling)

- Must be checked hot



Cooling System

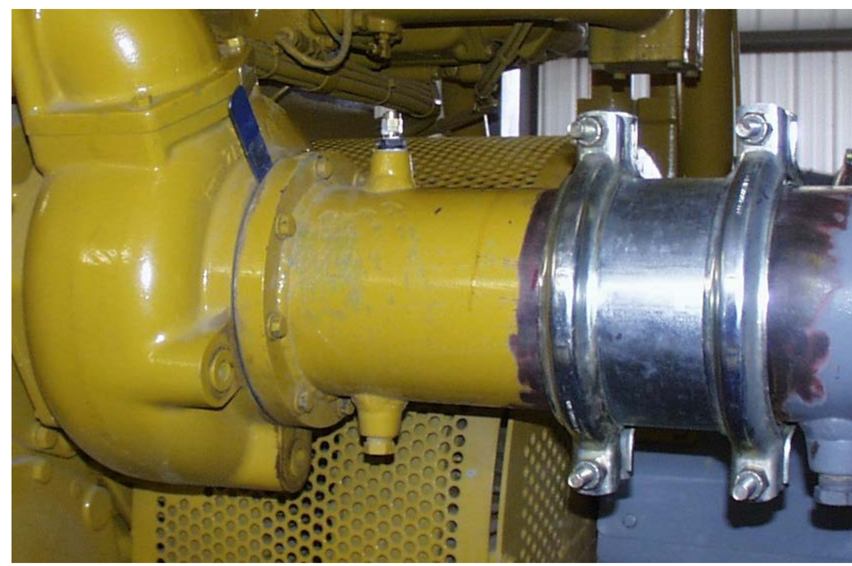
- Flexible connections are required; good alignment avoids stress on components and possible impact on engine alignment
- Locate thermostats for serviceability and to limit total circuit volume



Cooling System

- No sharp bends in piping; adds restriction and risk of cavitation in coolant pump

- Straight length before pump inlet allows use of debris screen



Engine Considerations
Engine External Connections

Air/Exhaust Systems

- Flexible connections are required; good alignment avoids stress on piping and possible impact on engine alignment

- Use smooth transitions and long radius bends to reduce system restriction; no "tees" please

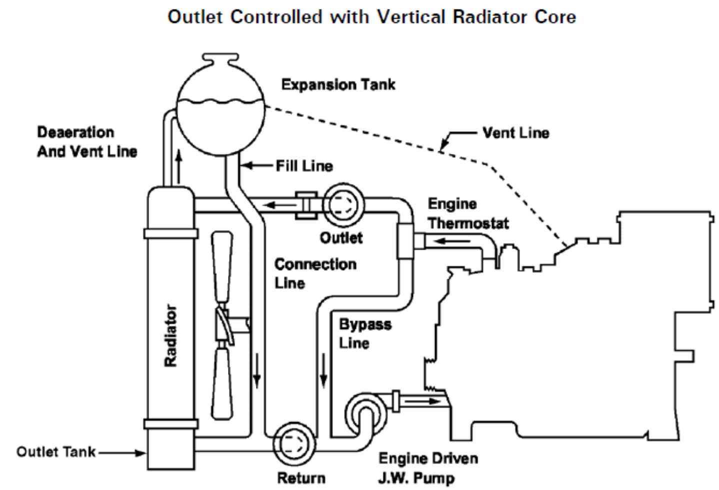
Air/Exhaust Systems

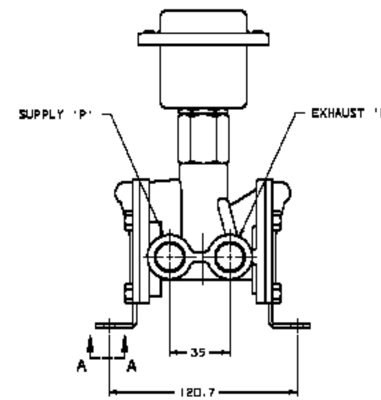
- Locate air cleaners for ease of servicing and best performance

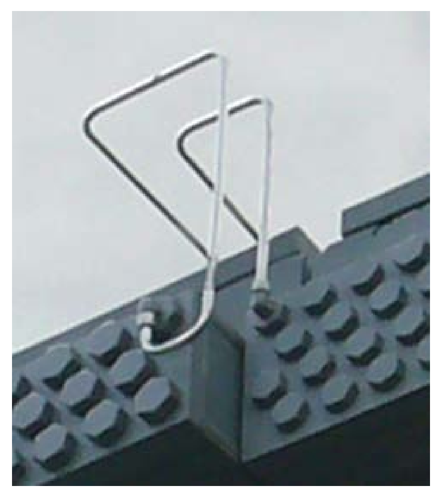
- Support piping from skid or building, not from the engine. Use locations that reduce the loads on turbos

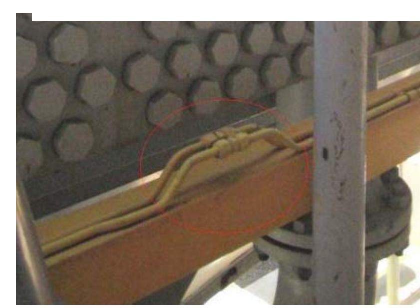
Venting

- Venting the cooling system is critical to avoid issues with trapped air/vapors
- Vent lines must be properly sized and carry a continuous upward slope with no inversions, pulling from all high points in the system
- Vent lines must be adequately supported against vibration, using flex connections were appropriate
- Starting and prelube systems also can require venting, be certain to review all manufacturer's recommendations/guidelines for best function
- Conduct a final review of the design of these systems …are you venting gas into the immediate area around the package? …are you tying high-pressure exhaust into low pressure vent systems?









Engine Considerations - Questions?

Packager Perspective

Frank Northrup, SEC Energy Products & Services

- Timeline
- Conditions
- Specifications
- Miscellaneous
- Best Practices

Packager Perspective

- **Timeline**
  - Shop Space
  - Major Components – Driver and Compressor Frame
  - Torsional and Pulsation Studies
  - Engineering Design
  - Installation, Start-up & Commissioning

- Conditions
  - Service – Transmission, Storage,
  - Site location
  - Elevation
  - Design ambient temperature & range
  - Pressure Ranges – Suction & Discharge - Current and Future
  - Volumes required
  - Gas sample – main supply & fuel gas

Packager Perspective

- <u>Specification</u>
  - Design requirements
  - Engineering standards
  - Inspection hold points
  - Equipment preferences, e.g., OEM
  - Exhaust emissions requirements (if engine)
  - Power availability (if motor)
  - Noise / sound attenuation requirements

- <u>Miscellaneous</u>
  - Heat trace, insulation, hot-starts
  - Shutdown panel – brand specific, PLC or other
  - Piping & pressure vessels – corrosion allowance, 100% X-ray, suction & discharge design pressures
  - Level controls – brand specific, no freeze or external dump valves, sight gauges or bulls eyes on vessels
  - Cooler – design approach, hail guard, auto-louvers, lay down beams, painted or galvanized
  - Limitations, such as width or height
  - Installation, start-up and commissioning assistance

- **Best Practices**
  - Concrete in skid under driver, frame and scrubbers
  - Center tie-downs for unit
  - Pulsation, torsional vibration studies

- **Best Practices**
  - **Shipboard cable in fiberglass trays**
  - **Supply exhaust, air intakes, oil and water**
  - **Turn-key site design services**
  - **Optimize shop time, minimize field time**

Packager Perspective - Questions?

System Design Consideration and Best Practices

Kelly Eberle, Beta Machinery Analysis

System Design Considerations Topics

Overall Project Management and Planning Issues:

1. Scope
2. Timing
3. Roles

Best Practice Considerations

1. Overview
2. Initial Activities
3. Skid and Foundation Design
4. Mechanical Design
5. Mechanical vs Thermal Design
6. Pulsation Design
7. Torsional Design
8. Installation
9. After Start-up

1. Scope (Section 7)

If you specifications states…

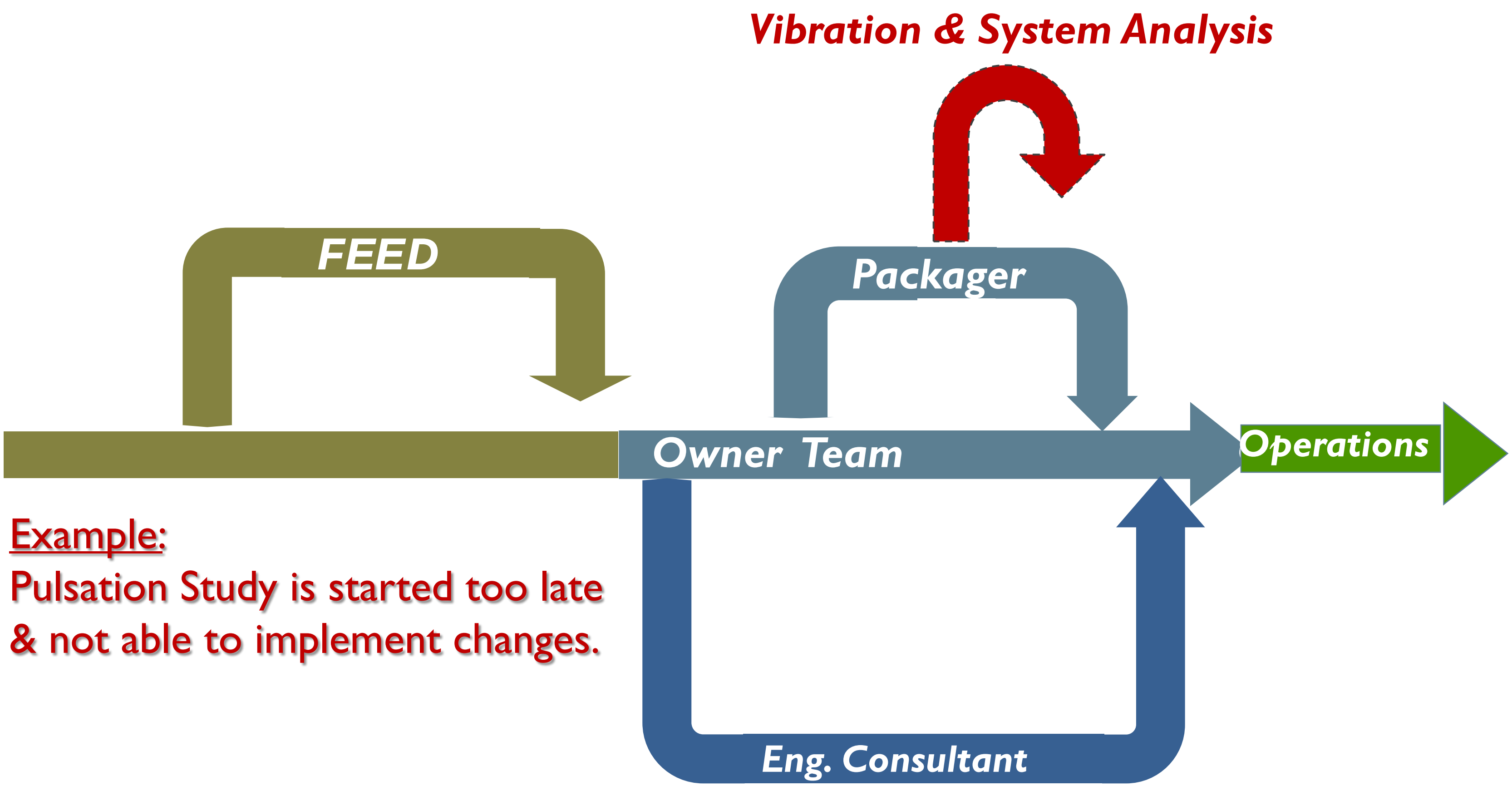
"Perform Pulsation and Vibration Study per API 618 (DA3)"

… it is NOT GOOD ENOUGH!

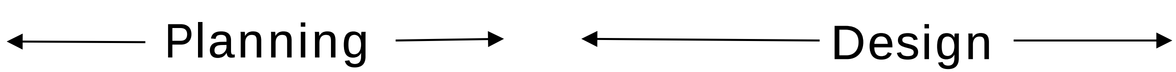
Specify Sufficient Details:

- Study scope
- Sufficient conditions
- Details for pulsation study
- Details for mechanical study
- …etc.

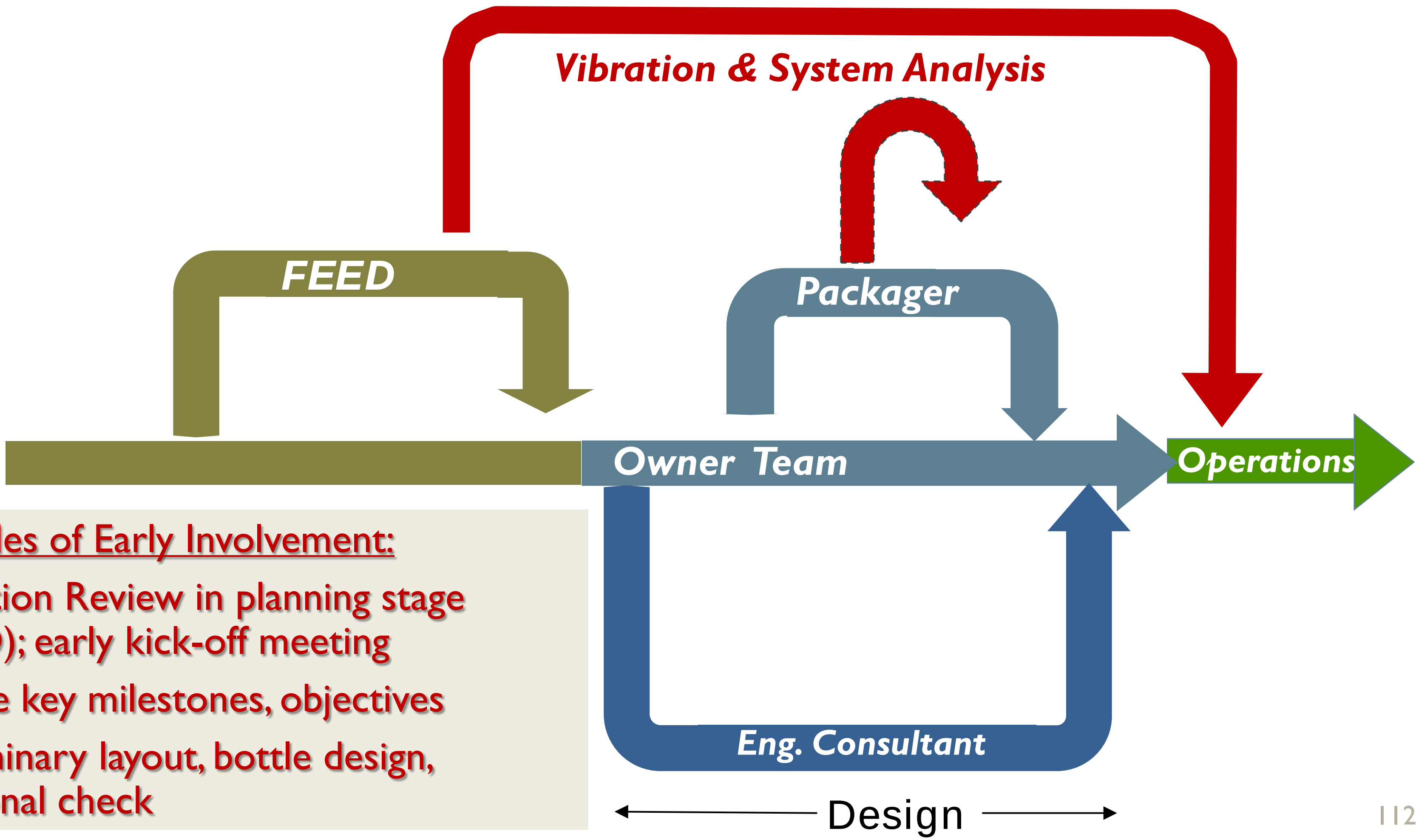
2. Timing (Section 7.1, 7.2)



Example:
Pulsation Study is started too late & not able to implement changes.



2. Timing – Early Involvement by Pulsation Consultant

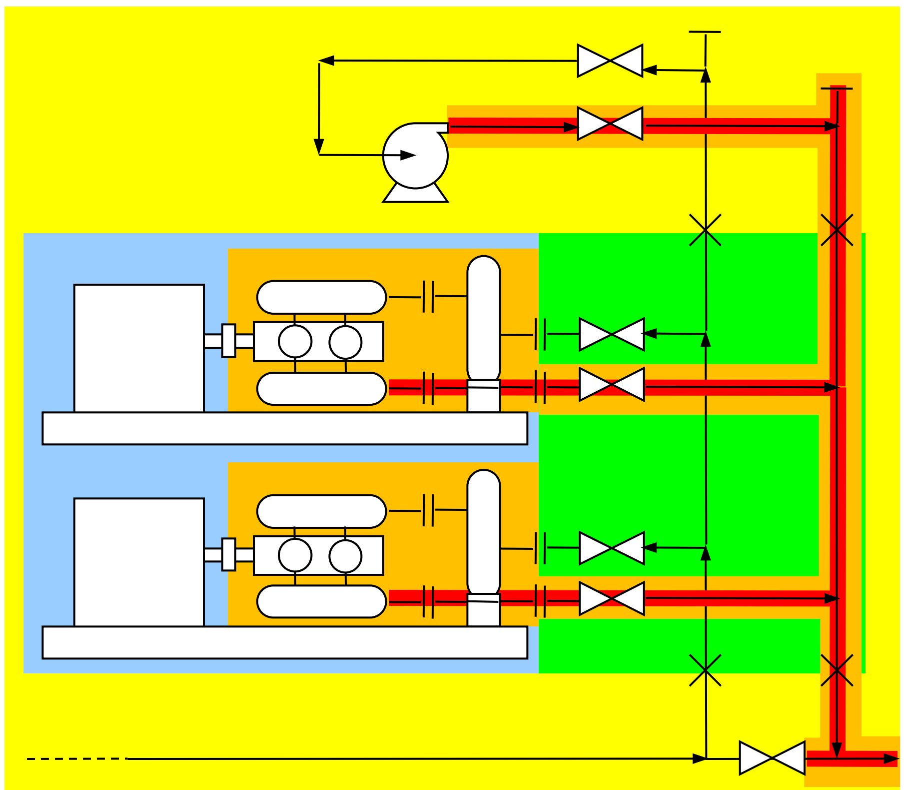


Examples of Early Involvement:

- Vibration Review in planning stage (FEED); early kick-off meeting
- Define key milestones, objectives
- Preliminary layout, bottle design, torsional check

3. Roles (Section 7.2)

"Vibrations Don't Stop at Skid Edge…"



Owner

Packager

Engineering firm

Vibration consultant

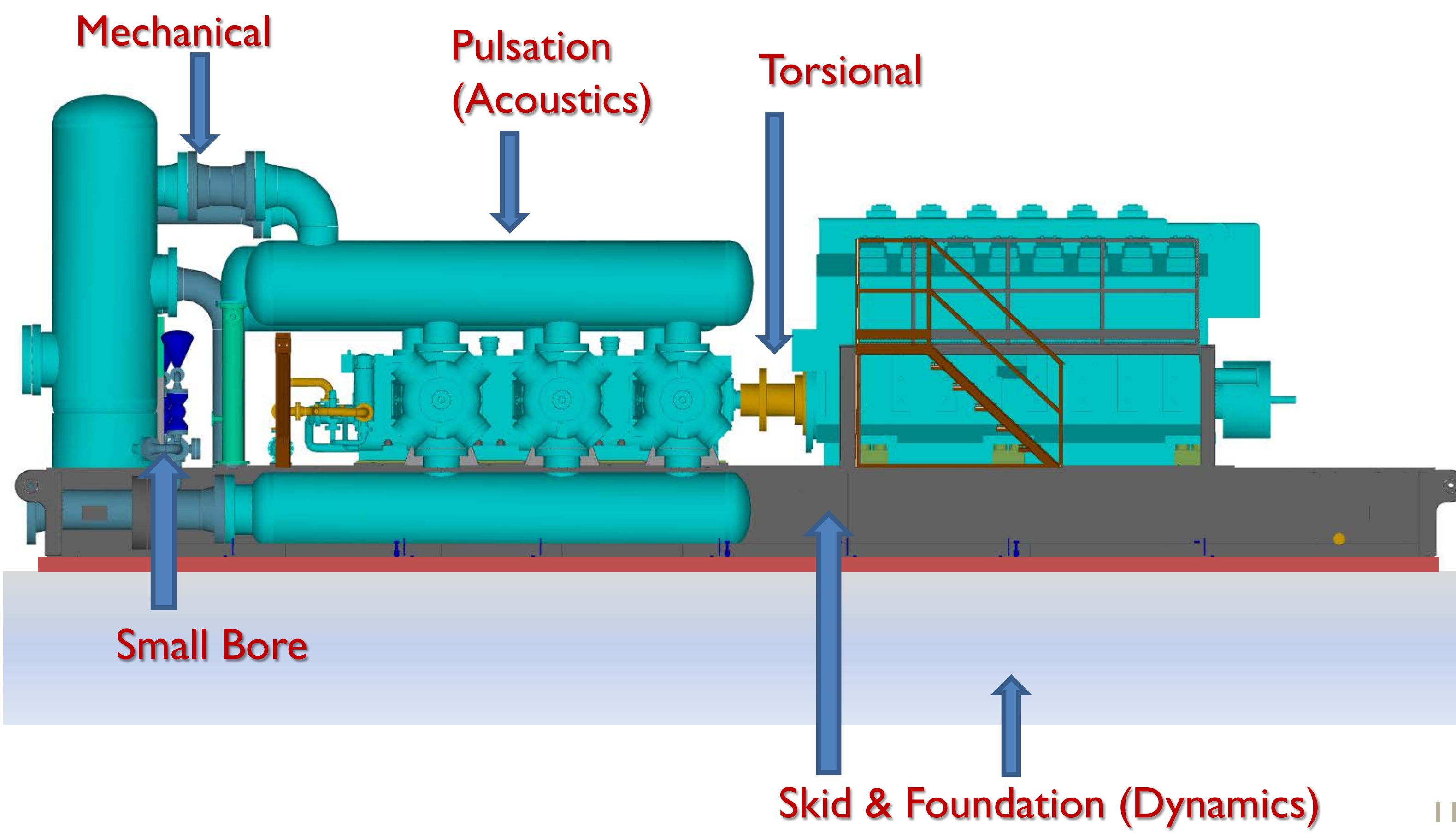
Many problems avoided when **Owners:**

- Hire vibration consultant directly, and
- Stay involved at key milestones

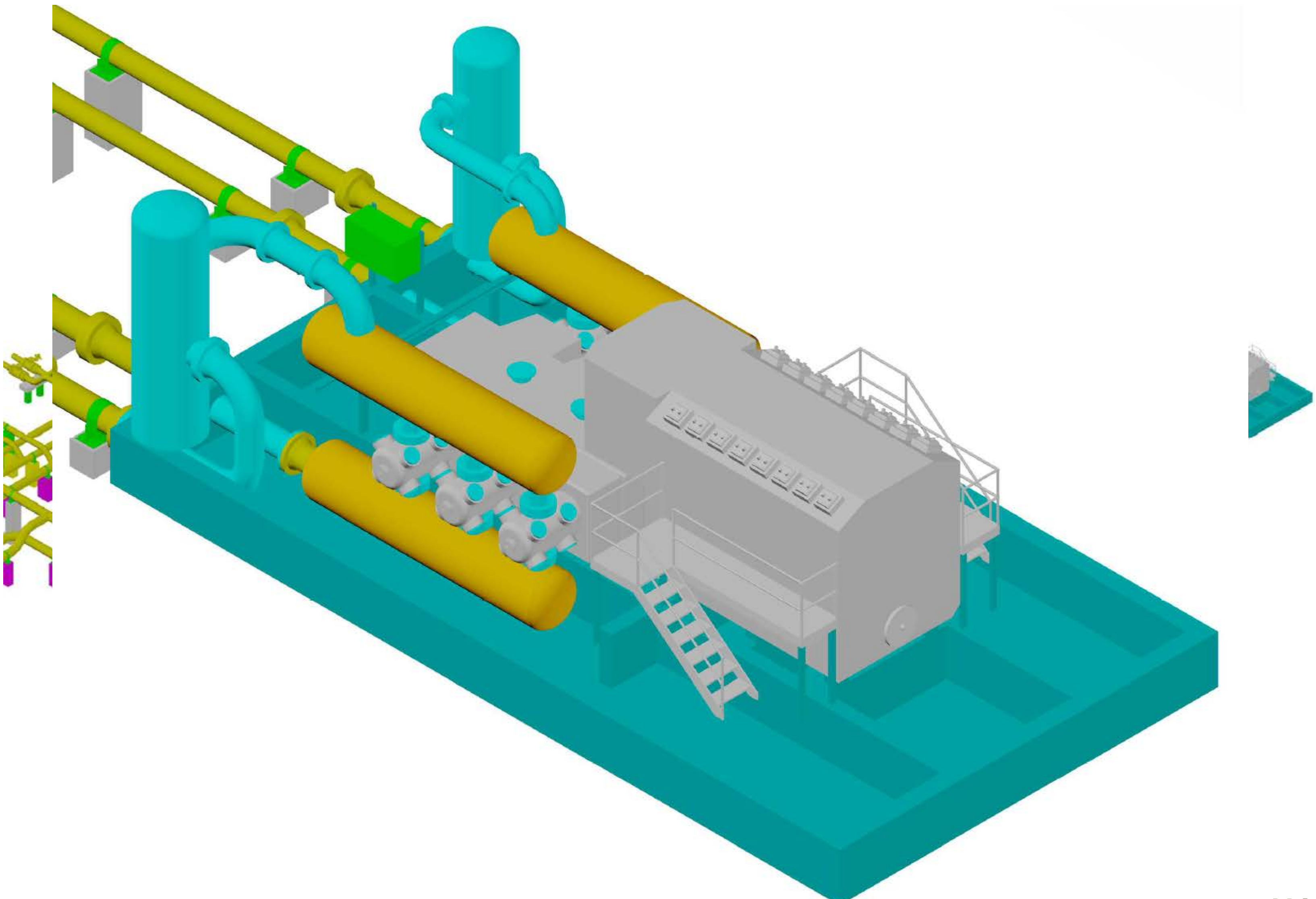
System Design: Best Practice Considerations

1. Overview
2. Initial Activities
3. Skid and Foundation Design
4. Mechanical Design
5. Mechanical vs Thermal Design
6. Pulsation Design
7. Torsional Design
8. Installation
9. After Start-up

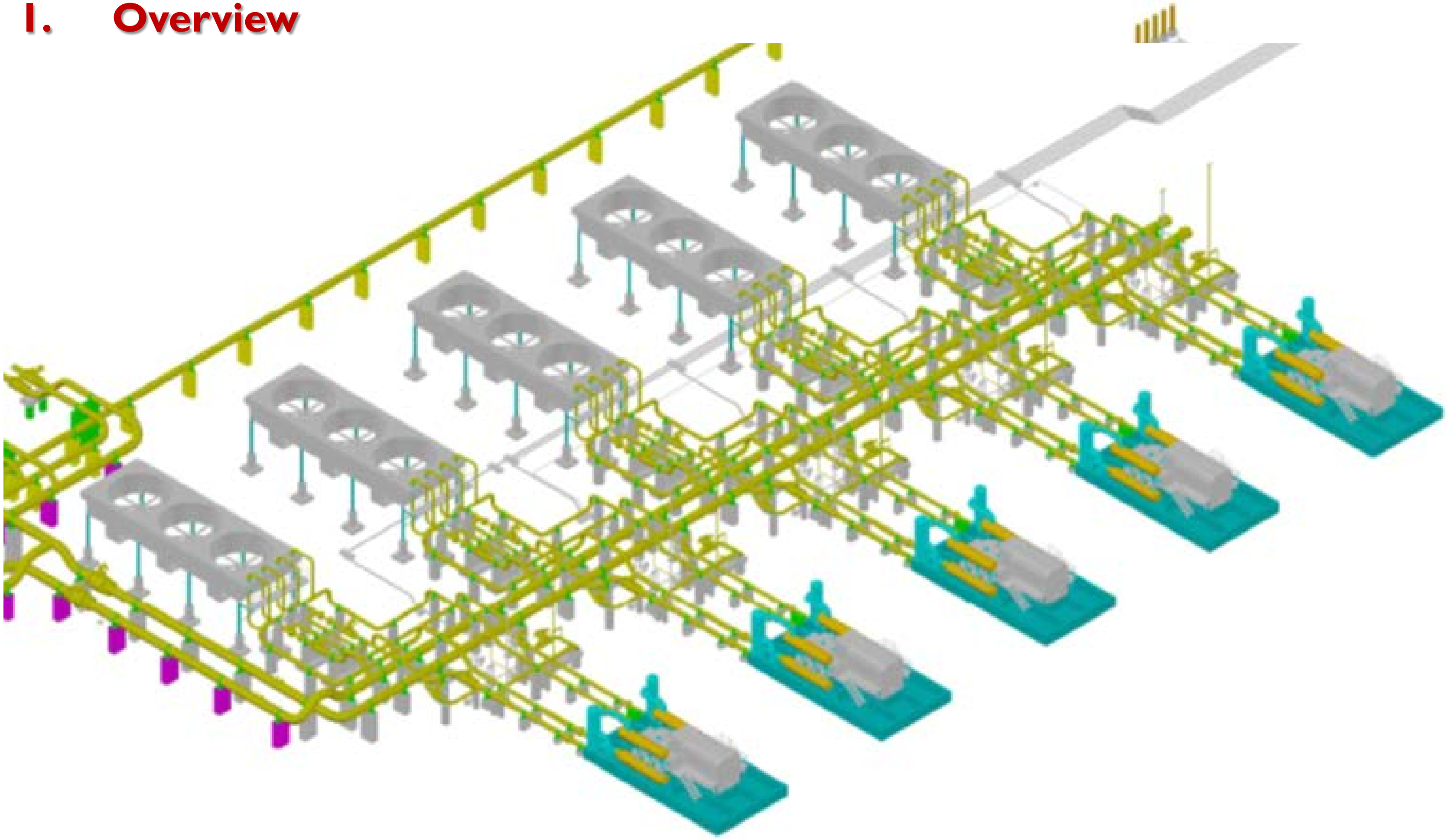
I. Overview: Vibration Risk Areas on Compressor(s) and Piping System (Section 7)



1. Overview



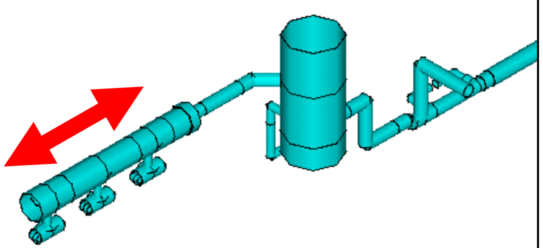
1. Overview



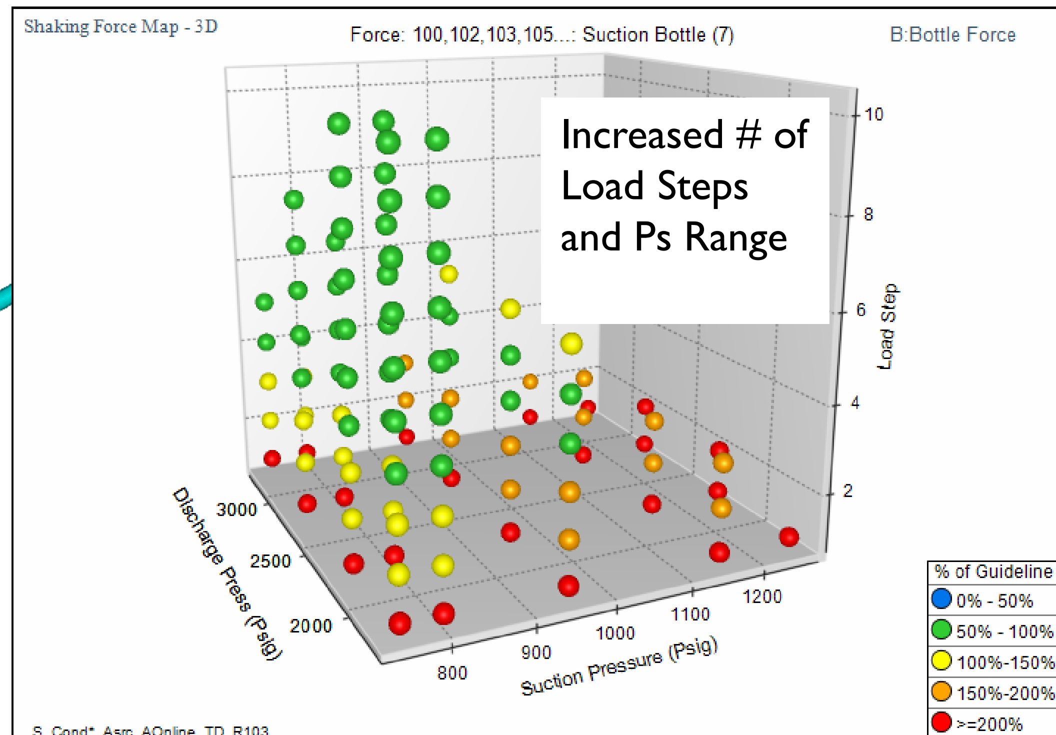
System Pressure Drop

2. Initial Activities (7.3)

- Agree on operating envelope
- Compressor loading
- Mounting plan (concrete, etc.)
- Initial Recommendations (Layout options, Bottles, Torsional)

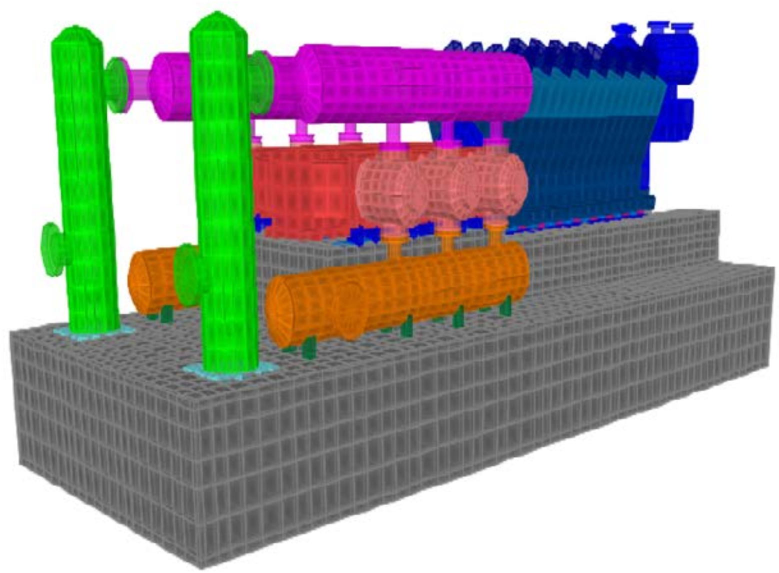


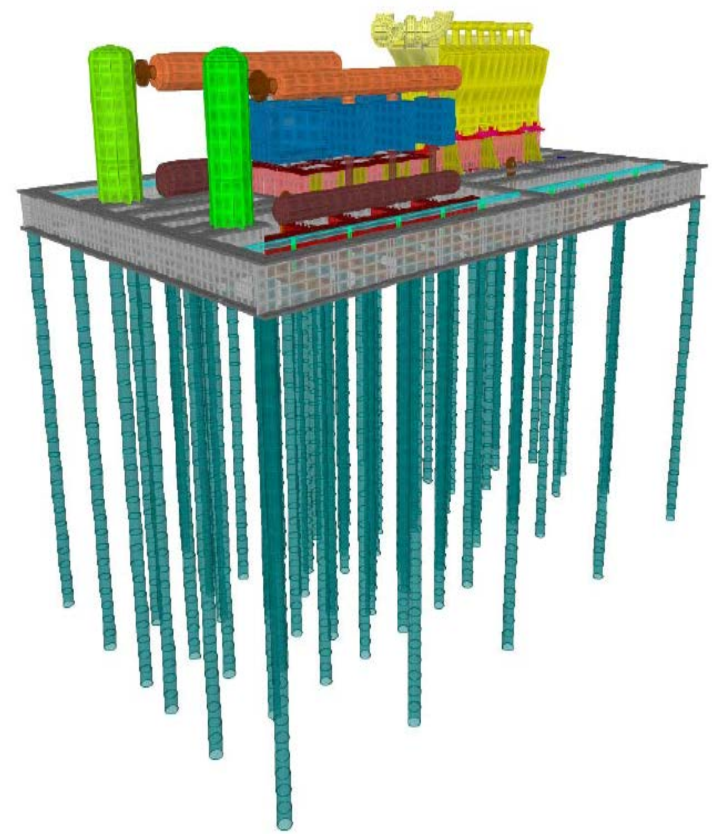
Bottle Shaking Forces >200% of Guideline. High Risk of Vibration Problem



3. Skid and Foundation Design (Section 6)

- Static and dynamic design considerations.
- Many best practices and industry experience included
- Block and skid mounted equipment
- Concrete block and pile foundation design (driven and screw piles)



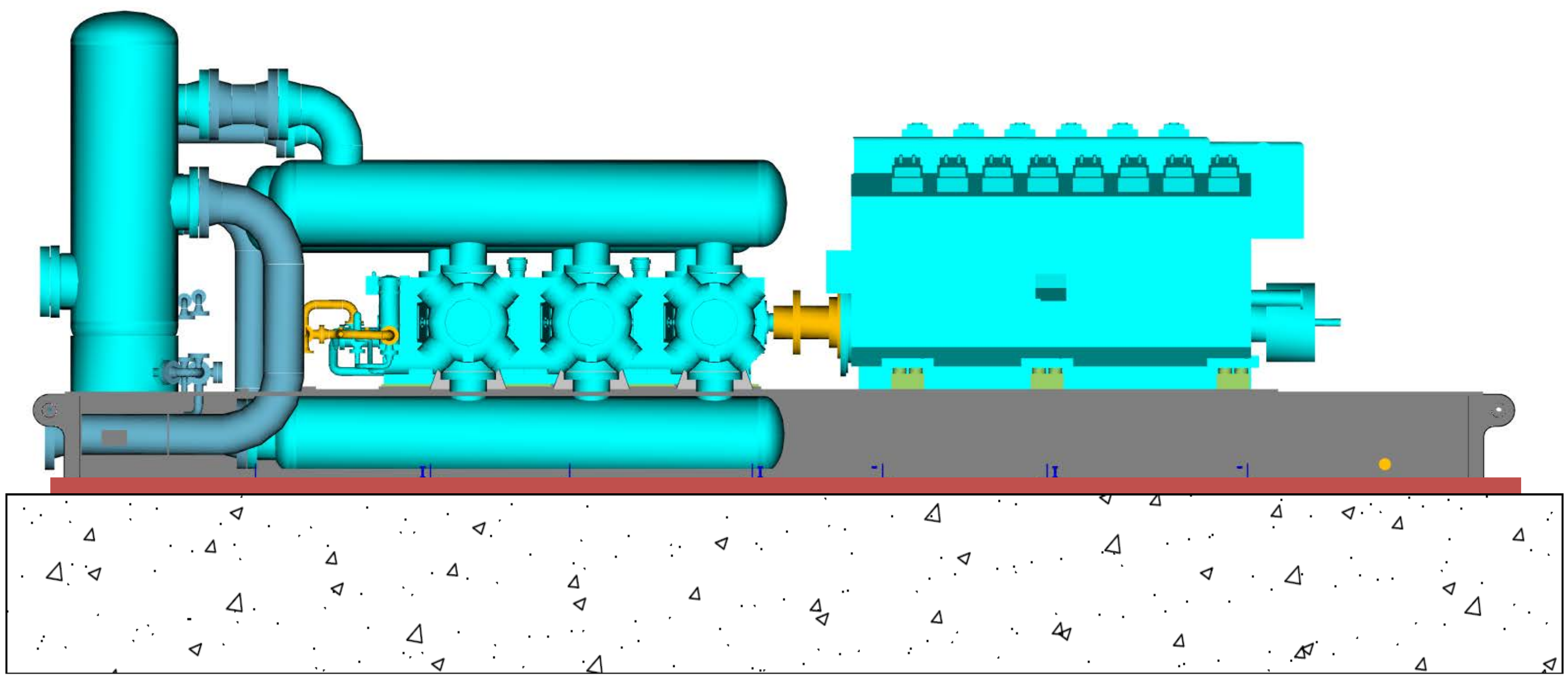


3. Skid and Foundation Design (Section 6)

- Steel Pile Foundations (driven or screw)
  - Skid design must be stiffer than block or slab mounted skid design
  - Pile design for static and **dynamic** design considerations.
  - Driven steel pile foundations used for many years on >6000 HP units
  - Screw pile foundations emerging. Designers and contractors must have experience and expertise in recip compressor applications.

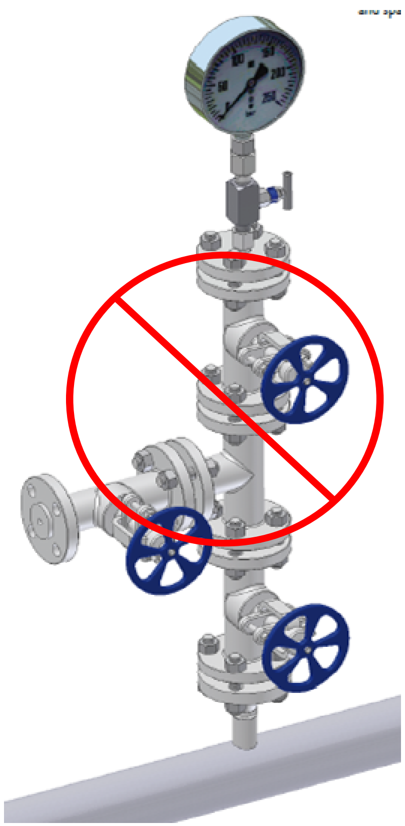
4. Mechanical Design (Section 7.3.3)

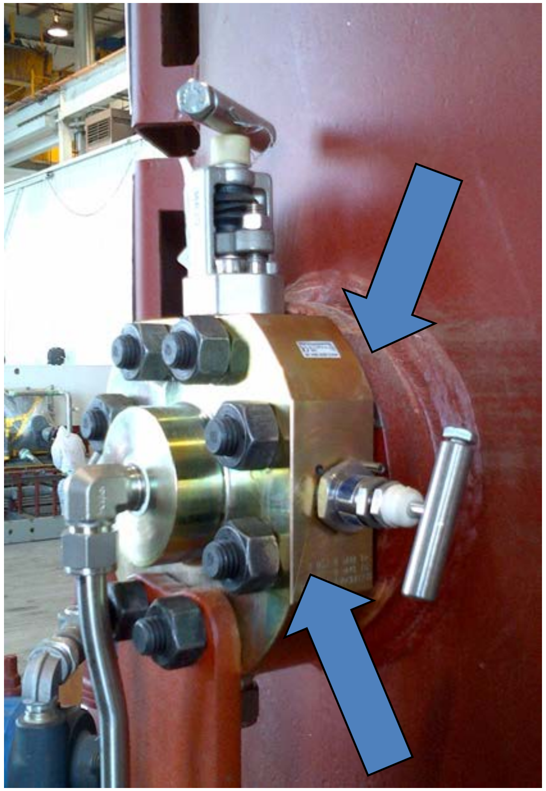
- Improve integrity of equipment mounted on the foundation and skid
- Avoid resonance at 1X and 2X run speed
- Also evaluate higher frequency forces (up to 6X)
- Strategy to **manage** resonance



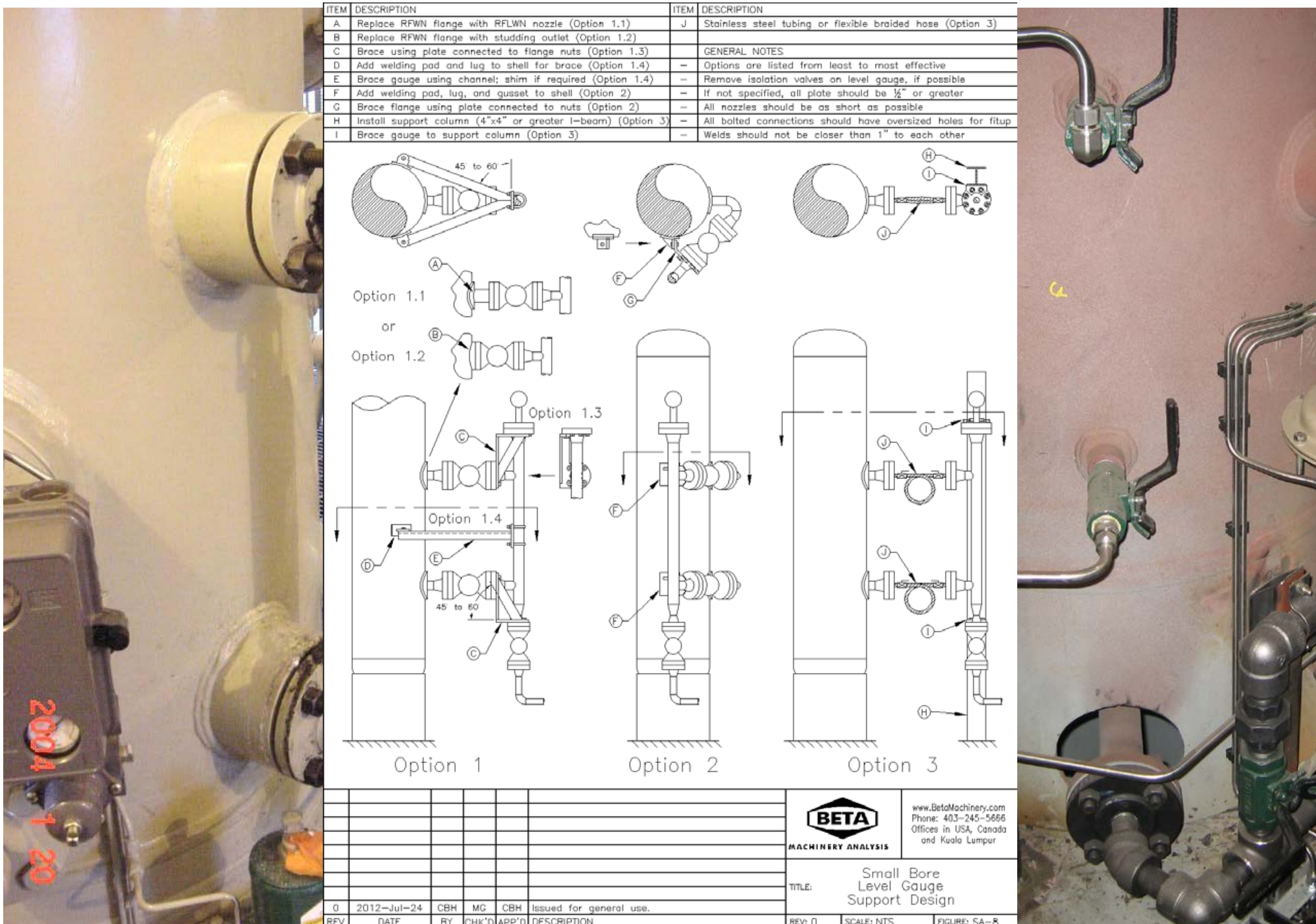
4. Mechanical Design - Small Bore Piping (Section 7.4.5)

- Avoid small bore where possible
- Re-orientate or re-configure to avoid vibration.
- Replace flanged block-and-bleed valves with Monoflange assemblies
- Use Studding Outlet instead of weld-o-let and nipple

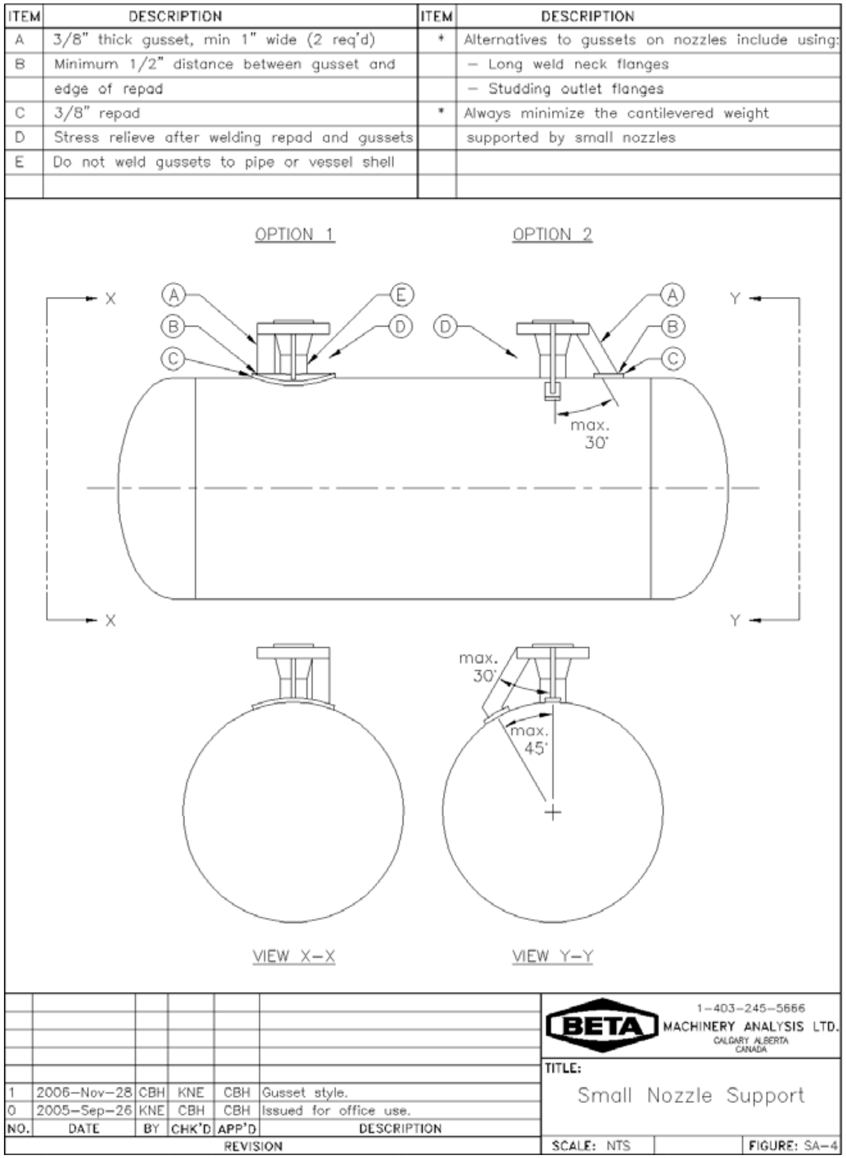


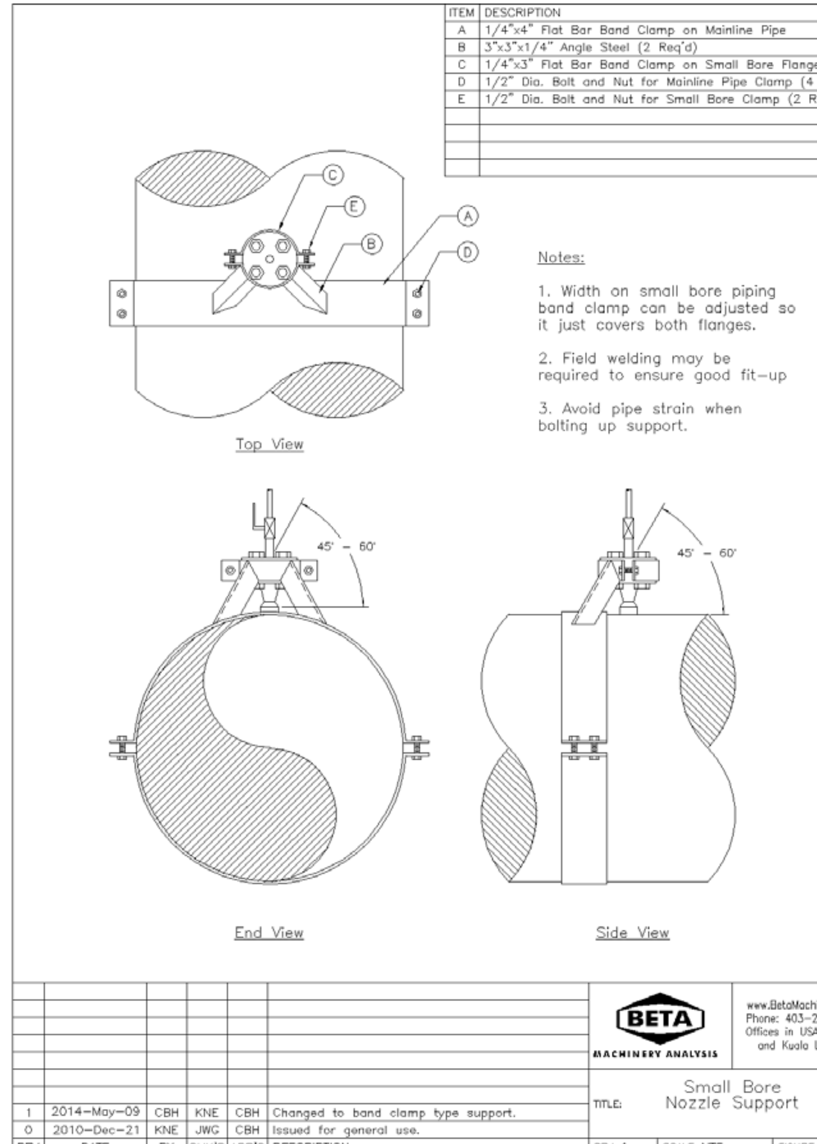


4. Mechanical Design – Scrubber Attachments



4. Mechanical Design – Bottle Attachments

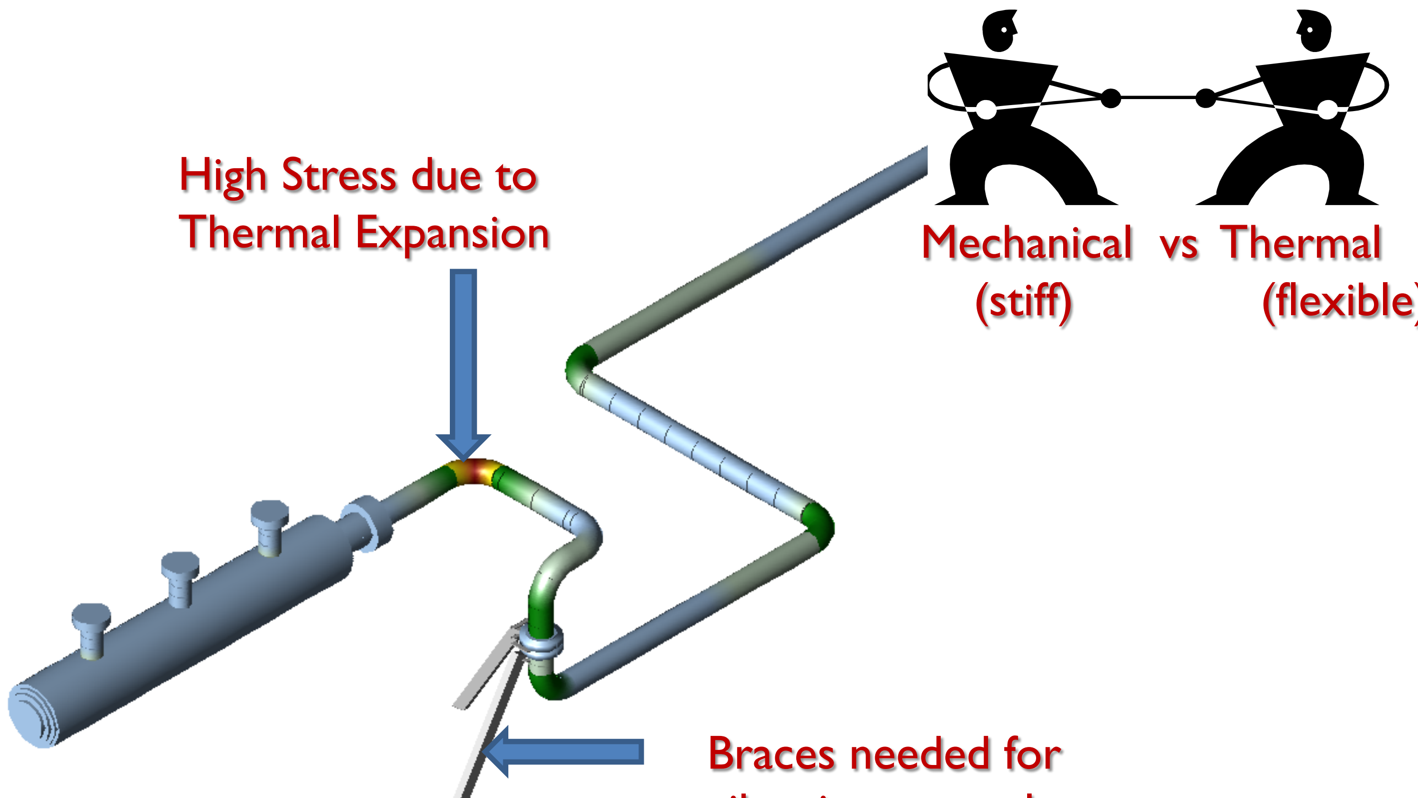




4. Mechanical Design - Small Bore Piping (Section 7.4.5)

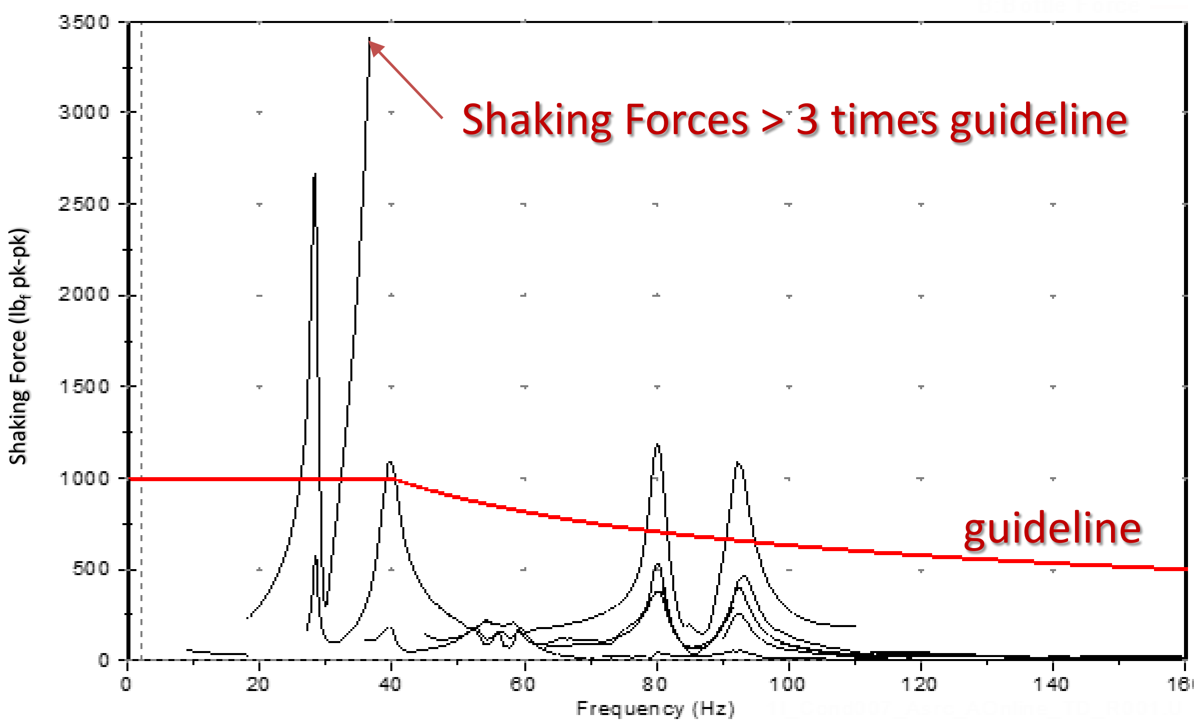
5. Mechanical and Thermal Design (Section 7.3.5)

- Different design considerations
- One group to evaluate both aspects



6. Pulsation Design (Section 7.3.2)

- Evaluate Pulsation and Shaking Forces
- Risk Management: Pulsations Control vs Pressure Drop vs Costs
- On-skid vs Off-skid
- Operating envelope (pressure range, load steps, speed)



Example: Excessive Piping Shaking Force

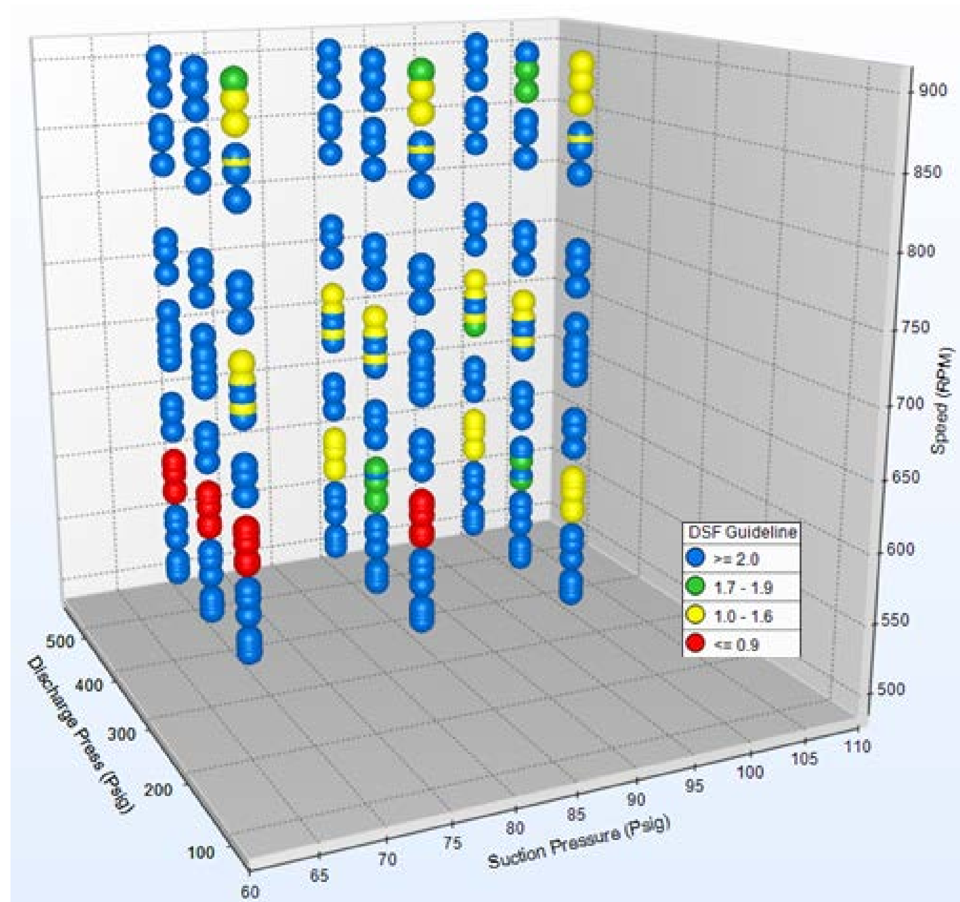
7. Torsional Analysis (Section 7.3.4)

- Analyze compressor-coupling-driver train to avoid failures of shaft and other driveline components

7. Torsional Analysis (Section 7.3.4)

- Analyze full operating map **PLUS** upset conditions
- Include tolerance band to consider fabrication and installation uncertainty
- Motor stub shaft to be the same diameter as the compressor stub

Risk of Failure at some pressures and speeds



8. Installation (Section 13)

- Ensure proper grouting and connection
- Pipe and vessel support adjusted to minimize strain
- Review all recommendations from studies have been installed

9. After Start-Up (section 12.4)

Two key tests to conduct

1. Torsional Test

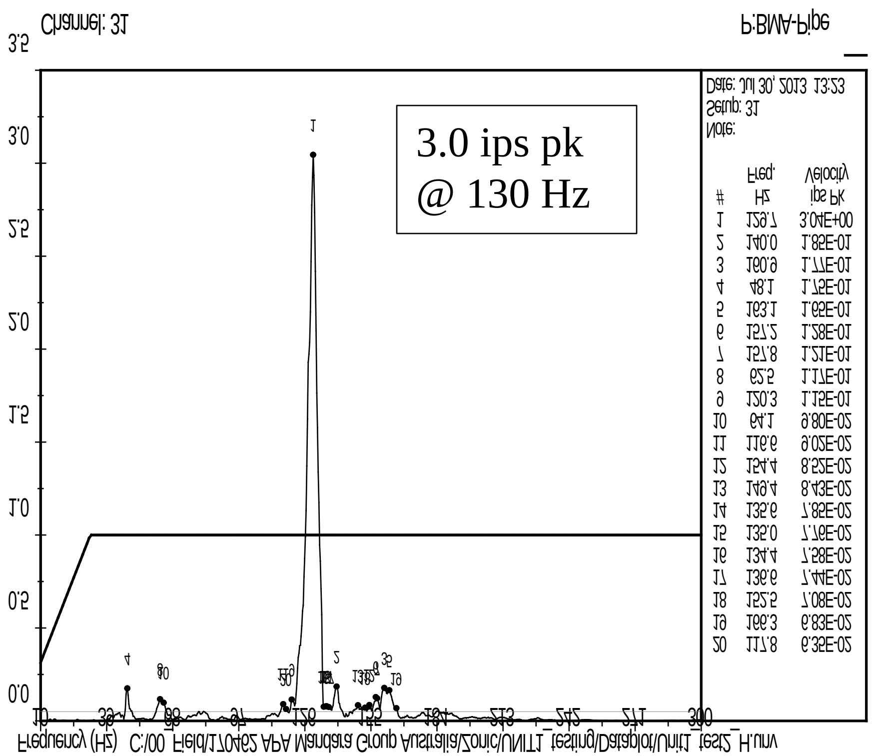
- Measure torsional natural frequencies and vibration amplitudes
- Particularly for variable speed drivers

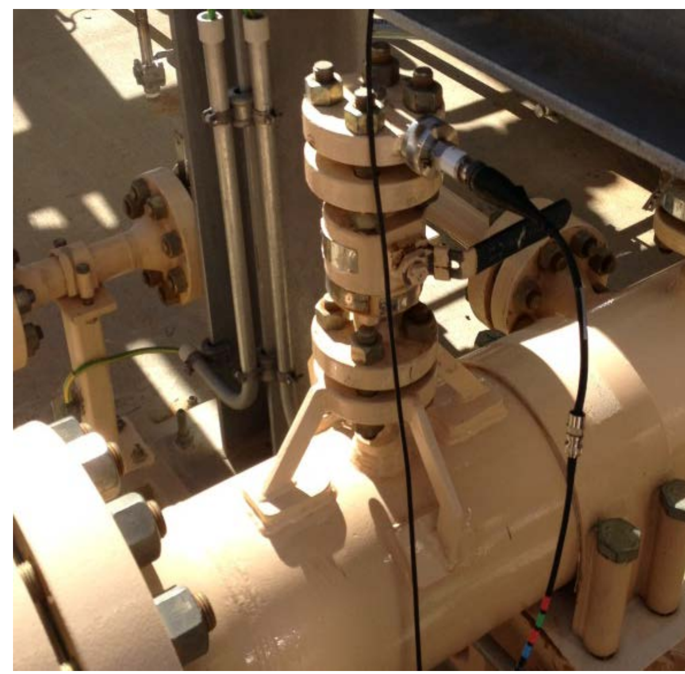
2. Vibration Assessment

- Measure vibration, pulsation and mechanical natural frequencies
- Vibration and pressure pulsation measurements should be recorded in a frequency spectrum format as a minimum.
- Overall vibrations (EFRC guideline – future ISO10816-8 standard) can be used as a preliminary screening tool. In extreme cases, problems could be missed or false problems identified

9. After Start-Up (section 12.4)

- Small Bore Piping (SBP) vibration test





Overall Project Management and Planning Issues
- Scope
- Timing
- Roles

Best Practice Design Considerations
- Expertise from a large group of industry experts, 100's of years of experience condensed into one document

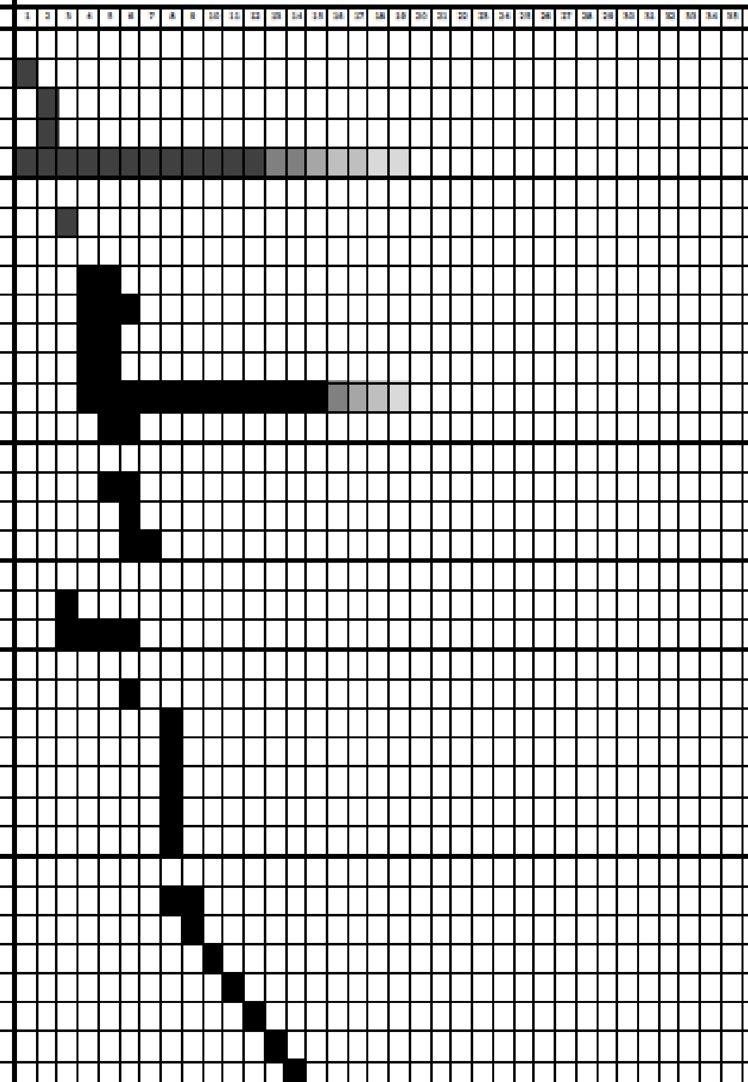
"Cost of the study is a small percentage of total costs, but can have a big impact on system reliability."

System Design Considerations – Questions?

Planned Project Sequence of Critical Events

Appendix 2.1: Recommended Project Sequence of Critical Events (p. 1/2)		
0.0		**Project Initiation and Planning**
	0.1	Identify need for a compressor project
	0.2	Select site
	0.3	Define required station flows and suction and discharge pressure ranges
	0.4	FERC permitting process
1.0		**Preliminary Equipment Sizing**
	1.1	Determine the numer and size of compressor units
	1.2	Determine driver type - electric or natural gas engine
		Electric: A. Select preferred motor vendor(s) and complete initial sizing
		B. Define power requirements and confirm utility company service
		Engine: A. Select preferred engine make(s) and model(s)
		B. Determine engine site power rating
		C. Environmental permitting
	1.3	Select compressor make(s) and model(s) to match driver
2.0		**Detailed Compressor Sizing**
	2.1	Determine the full required range of operating conditions
	2.2	Determine the most important or critical operating conditions (design points)
	2.3	Determine cylinder sizes and unloading approach
3.0		**Site Survey**
	3.1	Confirm site layout & accessibility
	3.2	Soil geotechnical testing & analysis
4.0		**Preliminary Design Analysis**
	4.1	Select vibration/pulsation design consultant
	4.2	Determine preliminary pulsation bottle sizing
	4.3	Initial design review of equipment configuration
	4.4	Initial design review of skid/foundation approach
	4.5	Initial design review of torsional risk
	4.6	Initial design review of overall plant piping arrangement
5.0		**Request for Proposal & Bid Evaluation**
	5.1	Prepare a detailed project specification
	5.2	Issue RFP to preferred packager(s) with firm due date
	5.3	Hold pre-bid RFP question & answer meeting with each bidder
	5.4	Receive all bids
	5.5	Review and evaluate bids, rate submittals & select acceptable bids
	5.6	Bid clarification meeting with each bidder (as required)
	5.7	Receive final bids net of any approved clarifications

Relative Timing --->



Planned Project Sequence of Critical Events (*continued*)

Appendix 2.1: Recommended Project Sequence of Critical Events (p. 2/2)			Relative Timing --->
6.0		Packager & Contractor Selections	
	6.1	Select packager and issue PO with complete scope & all supporting specifications	14
	6.2	Order driver and compressor (by packager or occasionally other)	15
	6.3	Select plant/building engineering consultant	13
	6.4	Select building contractor	15
7.0		System Design	
	7.1	Reconfirm operating conditions	15
	7.2	Size and order coolers	16
	7.3	Fnalize unloading scheme and control requirements	17
	7.4	Complete torsional analysis	18
	7.4	Complete coupling selection, final driver shaft details, flywheel requirements	18
	7.5	Complete package & skid design layout for review	19
	7.6	Complete preliminary plant piping layout	20
	7.7	Finalize pulsation bottle sizing	18
	7.8	Review equipment accessibility**	20, 24–25
	7.9	Complete pulsation study, mechanical analyses, skid dynamics analysis	18–21
	7.9	Review pulsation/vibration study and affects on system performance**	22
	7.10	Complete piping flexibility analysis	23
	7.11	Complete building layout, stairs, platforms, crane access, etc.	24
	7.12	Complete final plant design	24
	7.13	Update off-skid pulsation and piping analysis with final design details	25
8.0		Fabrication/Construction	
	8.1	Fabricate package	20–24
	8.2	Inspect package and conduct small bore piping MNF testing	25
	8.3	Package control system and sequencing testing	24–25
	8.4	Test package	25
	8.5	Install foundation	24–27
	8.6	Fabricate building	28–31
	8.7	Install package	28–29
	8.8	Complete process and utility piping	30–31
	8.9	Align package	32
9.0		Start-up & Commissioning	
	9.1	Cleaning, flushing and preparation for start-up	33
	9.2	Final inspection & checklist completion prior to start-up	34
	9.3	Conduct initial vibration screening & remediation if necessary	34
	9.4	Torsional Testing	34
	9.5	Performance Testing	35

** Consider any trade-offs before plant construction & completion of package fabrication.

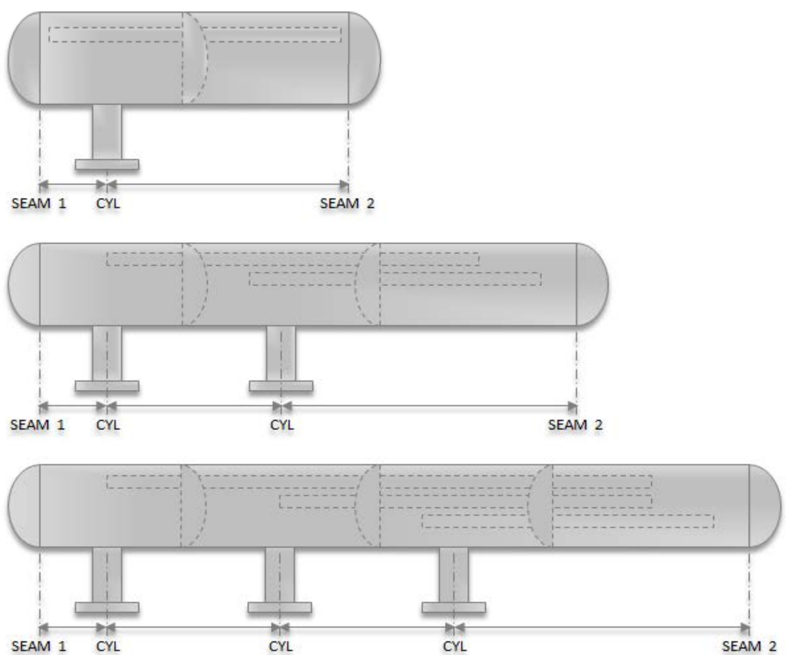
(pre-RFQ) Preliminary Bottle Sizing Tool

Preliminary Bottle Sizing for High Speed Compressor Packages in Natural Gas Tranmission and Storage
For Bidding Purposes Only

3.000	Number of Cylinders Manifolded
48.000	Cylinder Spacing, in
20.000	Cylinder Nozzle Nominal Diameter, in (Note 1)
1200.000	Design Pressure, psig
20000.000	Maximum Allowable Stress, psi (Note 2)
1.000	Longitudinal Joint Factor (E = 1.0)

48.000	Estimated Bottle OD, in
1.406	Minimum Bottle WT, in (Note 3)
12.000	Minimum Choke Tube Nominal Diameter, in
192.000	Estimated Seam-to-Seam Bottle Length, in
14.500	Seam 1 to Nearest Cylinder, in
81.500	Seam 2 to Nearest Cylinder, in

Note 1: For cylinder nozzle diameters up to 20-inch nominal
Note 2: Maximum allowable stress per ASME BPVC Section II, Part D, Table 1A
Note 3: Shell thickness calculations per ASME BPVC Section VII, Appendix 1-1 (a)



Bid-Evaluation Spreadsheet Tool

**Compression Bid Tab (EXAMPLE ONLY)

		†† Compr. Purch. Spec. No.	Company Spec. Requirements	Max Score	Vendor A	Score	Vendor B	Score
Technical	††General 3.0							
	Engine		CAT 3512B	20	Company Spec	20	Company Spec	20
	Compressor Frame		Ariel JGT/4	20	Company Spec	20	Company Spec	20
	Compressor Cylinders		6 3/8"TU (6.000" Bore)	10	Company Spec	10	Company Spec	10
	Ambient		105 F	20	Company Spec	20	Company Spec	20
	Altitude		500 ft	20	Company Spec	20	Company Spec	20
	††Engine 4.0							
	Engine Emissions	4.4	.5 Nox, 2.0 CO, .7 VOC, EPA, TCEQ	10	Company Spec	10	Company Spec	10
	Engine Starter	4.8	150 psig Turbine, Full Load Start	10	Company Spec	10	Company Spec	10
	Fuel Gas	4.9	150 psig supply, FG scrubber	10	Company Spec	10	Company Spec	10
	Air Intake	4.10	By vendor, 40 linear ft duct, mirrored	10	Company Spec	10	Company Spec	10
	Intake Silencer	4.10.7	Critical / Hospital Grade	10	Company Spec	10	Company Spec	10
	Exhaust System	4.11	By vendor, 40 linear ft duct, mirrored	10	Company Spec	10	Company Spec	10
	Exhaust Silencer	4.11.1	Critical / Hospital Grade	10	Company Spec	10	Company Spec	10
	Exhaust Stack	4.11.10	Silencer w/ Catalyst, Wind / Seismic	10	Company Spec	10	Company Spec	10
	Exhaust Line Sample Ports	4.11.18	Up / Downstream of Catalyst	10	Company Spec	10	Company Spec	10
	Jacket Water Surge Tank	4.12.2	Provided by Vendor	10	Company Spec	10	Company Spec	10
	Kim Hot Start Jacket Water Heater	4.12.10	480/3/60 Power, 24 VDC on/off	10	Company Spec	10	Company Spec	10
	Lube Oil System	4.13	System w/ Filters, Meters, Valving	10	Company Spec	10	Company Spec	10
	Pre / Post Lube Pump	4.13.2	Engine and Turbocharger	10	Company Spec	10	Company Spec	10
	Fire Safe Oil Regulator	5.13.3	Provided by Vendor	10	Company Spec	10	Company Spec	10
	Kim Hot Start Engine Oil Heater	4.13.6	480/3/60 Power, 24 VDC on/off	10	Company Spec	10	Company Spec	10
	Kim Hot Start Engine Oil Heater	4.13.6	480/3/60 Power, 24 VDC on/off	10	Company Spec	10	Company Spec	10
	Engine Barring Device	4.14	To Provide CAT Standard	10	Company Spec	10	Company Spec	10
	††Compressor							
	Compressor Packing Vents	5.7	To Match Figure 1	10	Company Spec	10	Company Spec	10
	Pneumatic Unloading Devices	5.8	Provided by Vendor	10	Company Spec	10	Company Spec	10
	Kim Hot Start Heater for Compressor Oil	5.1	480/3/60 Power, 24 VDC on/off	10	Company Spec	10	Company Spec	10
	Compressor Crankshaft deflection	5.11	50% of MFG allowable	10	Company Spec	10	Company Spec	10
	Divider Block Lubricator System	5.12	System w/ Filters, Meters, Valving	10	Company Spec	10	Company Spec	10
	Pre / Post Lube Pump	5.13	Provided by Vendor	10	Company Spec	10	Company Spec	10
	Sampling Points	5.14	1/4" NPT	10	Company Spec	10	Company Spec	10
	Fire Safe Oil Regulator	5.15	Provided by Vendor	10	Company Spec	10	Company Spec	10
	TDC on Engine Flywheel	5.18	TDC of cylinder #1	10	Company Spec	10	Company Spec	10
	Compressor Cylinders	5.19	With Kiene Valve KN-22	10	Company Spec	10	Company Spec	10
	††Torsional Analysis							
	Torsional Analysis	6.0	Purchased Separately by Company	10	Company Spec	10	Company Spec	10
	††Coolers							
	Coolers Configuration	7.1.1	Skid Mounted, Engine Driven	10	Company Spec	10	Company Spec	10
	Cooler Noise	7.1.8	10,000 fpm, 85 dBA	10	Company Spec	10	Company Spec	10
	EJW / AW Coolers	7.2	110% Surface	10	Company Spec	10	Company Spec	10
	Process Gas Coolers	7.3	110% Surface, .002 Fouling Factor	10	Company Spec	10	Company Spec	10
	Headers	7.3.9	1/16" CA, 2x API 661 Loads	10	Company Spec	10	Company Spec	10
	††Gas Piping							
	Acoustic and Mechanical Studies	8.2	Purchased Separately by Company	10	Company Spec	10	Company Spec	10
	Gas Pipe spec's and Standards	8.3	F = .04, S/D MAOP = 800/1200 psig	10	Company Spec	10	Company Spec	10
	Compressor Bottles	8.4	Sized per Company Spec.	10	Company Spec	10	Company Spec	10
	Cleaning of Pipe and prep for Shipping	8.5	Hydroblasted, Plywood on Openings	10	Company Spec	10	Company Spec	10
	Pressure Taps and Thermowells	8.8	6000# TOL, AGCO Needle Valves	10	Company Spec	10	Company Spec	10
	Bolts	8.9	Per M0003-OCT-04-02	10	Company Spec	10	Company Spec	10
	Valves	8.10	Per M0001-SEP-10-02	10	Company Spec	10	Company Spec	10

Best Practices for Specifying & Procuring a Successful Large, Hi-Speed Reciprocating Compressor Package

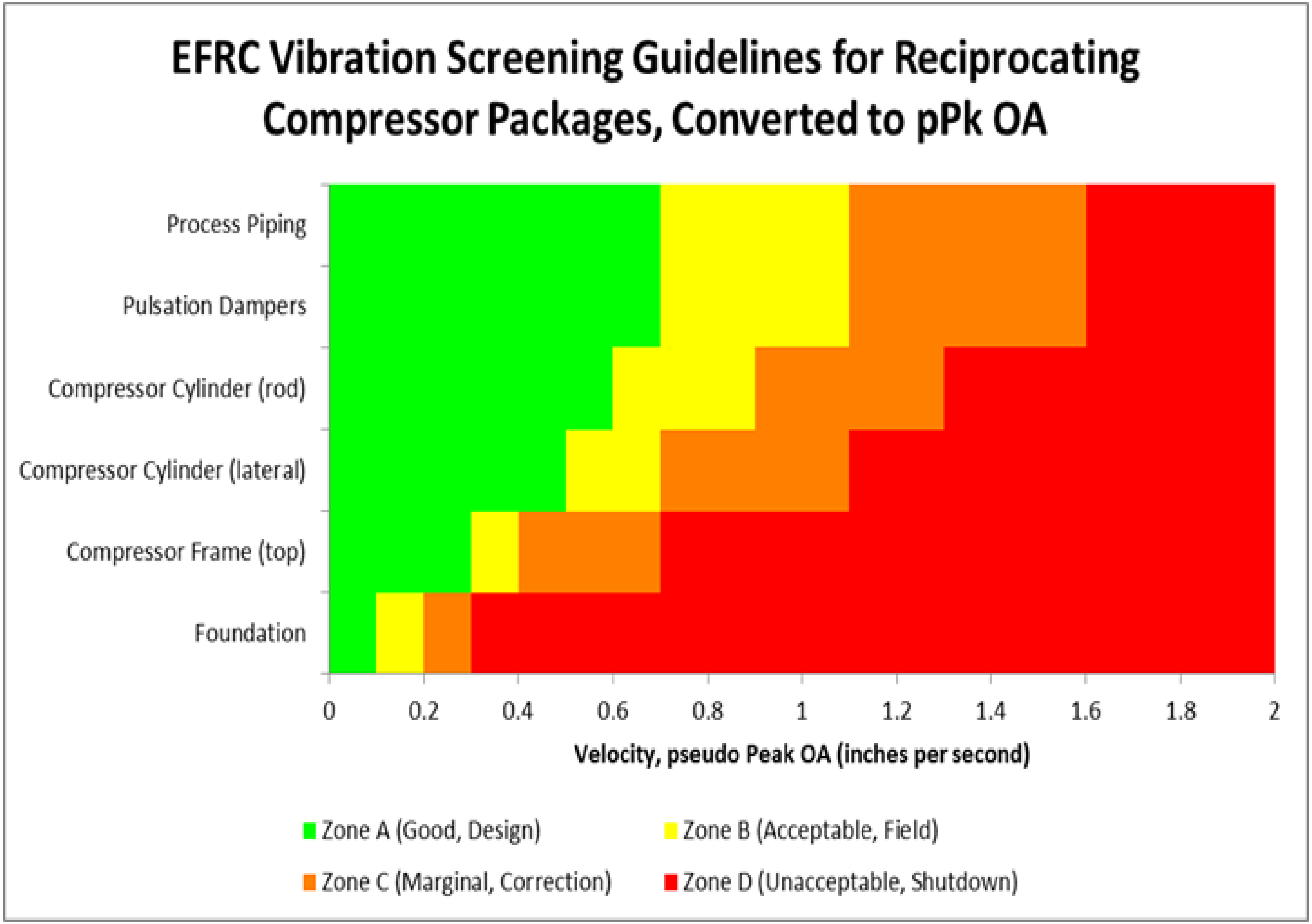
GMC Oct. 7, 2014

Bid-Evaluation Spreadsheet Tool (continued)

	Weld inspection	8.13.1	100% Radiographic	10	Company Spec	10	Company Spec	10
	Hydrostatic Tests	8.13.3	1.5 x MAOP for 8 hours	10	Company Spec	10	Company Spec	10
	††Skids							
	Vibracon Mounts	9.2	Not Acceptable	10	Company Spec	10	Company Spec	10
	Skid Top checkered steel plate	9.9	Seal Welded Over Entire Top of Skid	10	Company Spec	10	Company Spec	10
	Skid Oil Containment	9.11	Drip Lip, Skid Drains	10	Company Spec	10	Company Spec	10
	††Package Instrumentation and Electrical	10.0						
	Package Instrumentation and Electrical	10.0	To Match List in Appendix C	10	Company Spec	10	Company Spec	10
	††General							
	Painting	11.1	Prep, Paint, Primer. High Temp Exhaus	10	Vendor A Standard	0	Vendor B Standard	0
	Inspection	11.3	Co. has Right to Inspect at Any Time	10	Company Spec	10	Company Spec	10
	††Documentation							
	P&ID	13.1	30 Days ARO	10	Not Supplied for Approval	0	8 Weeks ARO	0
	Auto CAD	13.6	30 Days ARO	10	Not Supplied for Approval	5	2-4 Weeks ARAD, Prelim 30 Days ARO	5
	Job Books	13.4	Provided by Vendor	10	CD	10	CD	10
	Code Compliance Book	13.5	30 Days Prior to Shipment	10	Not Supplied	10	Company Spec	10
	*Technical notes		- List specific experiences from a technical perspective, feedback, quantity/quality of work	+/-	- Took exception to entire Company Purchase Spec. - Quoted some, did not quote other equipment listed in RFB.	-20		0
	Subtotal			600		555		575
Commercial	Bid Price		Lowest	180	$1,070,660	180	$1,174,809	164
	Option 1		FOB Shipping to Site	40	No Bid	0	$17,212	10
	Option 2		Start up Assistance	40	$10,000	40	$9,375	40
	Option 3		100% X-Ray on Vessels	20	No Bid	0	$5,840	20
	Option 4		PWHT on Bottles	20	No Bid	0	$2,413	20
	Option 5		Witness Run Test	20	No Bid	0	$4,530	20
	Option 6		1/8" Corrosion Allowance on Cooler	20	No Bid	0	$5,271	20
	Option 7		Two Scrubbers in lieu of one	20	No Bid	0	$16,730	20
	Option 8		Ship Board Style Cable	20	No Bid	0	$16,514	20
	T's & C's		Company STD	40	10/25/20/30/15	40	15/25/25/25/10	40
	Lead Time		Lowest	180	30 Weeks ARO	162	26-28 Weeks ARO	180
	*Commercial notes		- List specific experiences from a commercial perspective, feedback, accuracy of bids, size/frequency of ECR's	+/-	- After bidding process had concluded, stated in phone conversation that price to comply with Company spec ~$200,000.	0	- T's & C's to be negotiated with contract coordinator. Negotiated terms less than 1 year ago, process now expected to be more efficient.	10
	Subtotal			600		422		564
General	*General notes		- List additional details as they are relevant	+/-	- Provided bid 1 week past deadline. - Attention to detail, communication was severely lacking.	-20	- Provided excellent support, customer service during bidding process. - Flexible and responsive to Company requests.	20
	Contact Information		The Man Company Energy 1234 Freeway, Suite 1000 Financially Responsible, TX. 54321 Phone: 123-456-7890 Direct: 123-456-7890 The.Man@Company.com	-	Peasant A Vendor A 1234 Freeway, Suite 1000 Dead Broke, CA 54321 Phone: 123-456-7890 Direct: 123-456-7890 peasant.a@Vendor A.com	-	Peasant B Vendor B 1234 Freeway, Suite 1000 Chapter 11, CA 54321 Phone: 123-456-7890 Direct: 123-456-7890 peasant.b@Vendor B.com	-
	Subtotal			0		-20		20
	Total Score			1200		957		1159
	% of Perfect Score			100.0%		79.8%		96.6%

Notes: * Indicates key paramter that may be a negotion point.
** This is a sample bid evaluation spreadsheet adapted from an actual spreadsheet provided by Atmos Energy as an example only. Bid winner was selected based on rev 0 bid tab. Vendor B stated weeks later, verbally, that they could comply with most of Company' purchase spec for ~200k adder to their previous bid. The lower price would not have changed the outcome of the bid evaluation.
† Indicates key paramter where vendor may be rejected based on non-compliance.
†† Reference Compressor Purchase Specification.

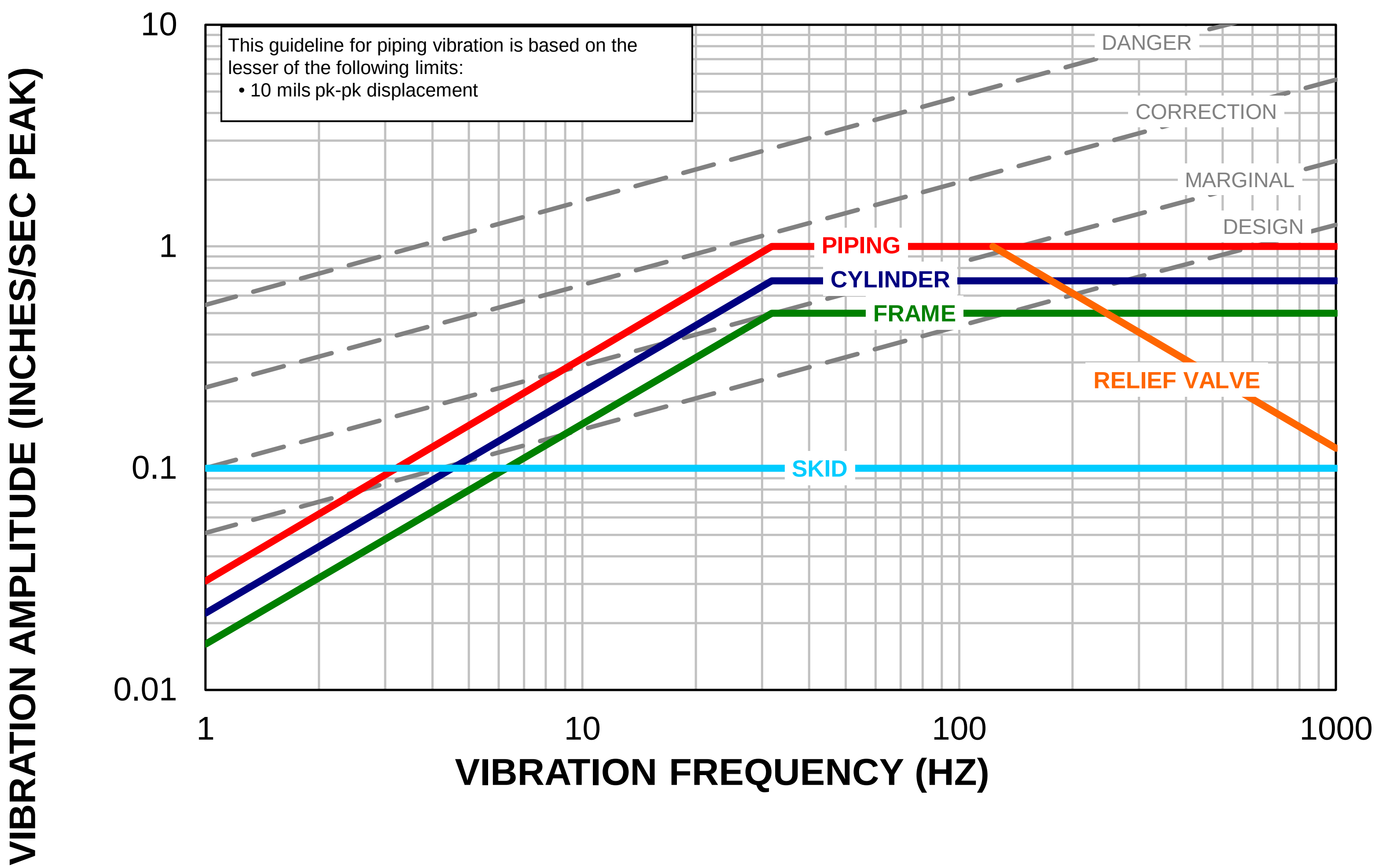
GMRC Vibration Screening Tool - EFRC



GMRC Vibration Screening Tool – Spectral Frequency Based

Guidelines for Reciprocating Compressors (1800 RPM max)

1. Cylinder guidelines are for axial and vertical directions.
2. Generic frame guideline. Consult OEM for recommended limits.
3. Solid Color Lines from Beta Machinery Analysis.



Summay & Wrap Up

Q/A & Open discussion
Wrap Up Summary

Please remember to complete The Course Evaluation Form!!

Best Practices for Specifying & Procuring a Successful Large, High-Speed Reciprocating Compressor Package

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