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

2014 Gas Machinery Conference Short Course

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

Course Purpose

- Introduces GMRC High Speed Compressor Package Guideline (soon to be released)
- Provides an initial (brief) overview & introduces some best practices.
- Intended to be the 1st installment of a 3-day GMRC course that will provide much more detail (to be introduced in 2015)
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
Engine Considerations
Engine Selection (fuel, site conditions)
TVA Validation of driveline
Engine mounting & Alignment
Engine external connections

Packager Perspective
What’s important from packager perspective?
What’s needed from the purchaser?
When is it needed?
Best practices

System Design Considerations
System Design Considerations
Best practices
Other

Summery & Wrap Up
Q/A & Open discussion
Wrap Up Summary

Adjourn
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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
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>>>>>
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

Don’t depend on good luck. It may not save you!
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
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 – Vibration Related Failure Examples
Shows need for some key design requirements.
Best Practices for Specifying & Procuring a Successful Large, Hi-Speed Reciprocating Compressor Package

Background – GMRC HS Package Guideline Project

Lots of Problems Observed – Alignment/Access/Maintainability
Shows need for some key design requirements.
Background – GMRC HS Package Guideline Project

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

![Image of GMRC HS Package Guideline Project](image_url)
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.
• 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.
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.

Basis for this short course.
Copies available for purchase at:
http://www.gmrc.org/hs-guidelines
1. SCOPE & INTRODUCTION
   1.1 Introduction & Background
   1.2 Management Components for a High-Speed Compr. Design Project
   1.3 Considerations and Design Practices
   1.4 Statutory Requirements
   1.5 Applicable References

2. PROJECT MANAGEMENT & SCHEDULE
   2.1 Project Manager
   2.2 Inspector
   2.3 Installation & Commissioning Coordinator
   2.4 Schedule

3. COMPRESSOR SYSTEM SELECTION & SPECIFICATION
   3.1 Definition of Transmission & Storage Station Capacity Requirements
      3.1.1 Gas Transmission Stations
      3.1.2 Gas Storage Stations
   3.2 Compressor Sizing and Selection
      3.2.1 Compressor & Driver Selection Considerations
      3.2.2 Compressor Unloading Considerations
      3.2.3 Preliminary Pulsation Bottle Sizing & Plant Layout
      3.2.4 Bid Evaluation Process
4. CAPACITY CONTROL
  4.1 Added Fixed Volumetric Clearance
  4.2 Cylinder End Deactivation
  4.3 Unloading Scheme Specification and Design
    4.3.1 Unloading Example
      4.3.1.1 4-Throw Compressor with No Unloading
      4.3.1.2 4-Throw Compressor with Unloading
      4.3.1.3 6-Throw Compressor with Unloading
  4.4 Control Algorithm Specification and Design

5. DRIVER AND COUPLING
  5.1 Engine Selection and Specification
  5.2 Electric Motor Selection and Specification
  5.3 Coupling Selection and Specification

6. SKID AND FOUNDATION
  6.1 Introduction
  6.2 Owner Project Management Considerations
    6.2.1 Responsibilities
    6.2.2 Milestones and Timing in Skid and Foundation Design
6. SKID AND FOUNDATION (continued)

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   6.3.1 Skid and Foundation Performance Criteria
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      6.3.2.1 Preliminary Foundation Design
      6.3.2.2 Soil Testing
      6.3.2.3 Foundation Static Design Requirements
      6.3.2.4 Foundation Dynamic Design Requirements
   6.3.3 Skid Design
      6.3.3.1 Skid Static Design Requirements
      6.3.3.2 Skid Dynamic Design Requirements

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   6.4.2 Foundation Design and Construction
      6.4.2.1 Concrete
      6.4.2.2 Reinforcing Bar (Rebar)
      6.4.2.3 Block Mounting
   6.4.3 Skid Design and Construction
      6.4.3.1 Concrete Fill
   6.4.4 Equipment Mounting
      6.4.4.1 Compressor Connection to Skid
      6.4.4.2 Skid Grout to Foundation
      6.4.4.3 Block Mounting
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   6.4.5 Skid and Foundation Modeling and Analysis Considerations
   6.4.6 Pile Design
6.5 Reference Documents and Links to Source Material

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   7.1.1 Sources of Reciprocating Compressor Vibration
   7.1.2 Effects of Dynamic Forces on Reciprocating Compressors
   7.1.3 Designing to Control Pulsation and Vibration
7.2 Owner Project Management Considerations
7.3 Analysis Categories and Descriptions
   7.3.1 Preliminary Design Review
      7.3.1.1 Compressor Application
      7.3.1.2 Specify Conditions for Pulsation/Vibration Study
      7.3.1.3 Preliminary Bottle Sizing, Pulsation Control Method
      and Piping Layout.
   7.3.2 Detailed Pulsation Control Design Analysis
   7.3.3 Mechanical Analysis
   7.3.4 Torsional Analysis
   7.3.5 Piping Thermal Flexibility Analysis
   7.3.6 Skid Dynamic Analysis
   7.3.7 Vibration Testing
7. PULSATION AND VIBRATION ANALYSIS & CONTROL (continued)

7.4 More Considerations and Best Practices

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7.4.1.2 Station and On-skid Piping Interactions
7.4.1.3 Orifices
7.4.1.4 Pipe Routing
7.4.1.5 Operating Range
7.4.1.6 Flow Velocity
7.4.1.7 Measurement Points

7.4.2 Mechanical Design

7.4.2.1 General Approach
7.4.2.2 Finite Element Model Accuracy
7.4.2.3 Forced Response

7.4.3 Torsional Analysis

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7.4.5 Guidelines for Small Bore Piping and Branch Connections

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7.4.5.2 Vibration Prevention
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   9.2 Liquid Cooling Systems
   9.3 Engine Fuel System
   9.4 Engine Starting System
   9.5 Equipment Mounting and Alignment Considerations
   9.6 Scrubber Design and Fabrication
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   9.8 Relief Valves (PSV)
   9.9 Process Piping
   9.10 Auxiliary Piping and Tubing
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   9.12 Mounting of Instrumentation and Control Devices
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   9.14 Skid, Equipment and Building Layout

10. EQUIPMENT ACCESSIBILITY AND MAINTAINABILITY

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      11.2.1 Minimum Engine Instrumentation
      11.2.2 Minimum Compressor Instrumentation
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   12.2 Recommended Shop Testing
   12.3 Installation Monitoring and Inspection
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         12.4.2.1 Vibration Screening (based on EFRC and ISO)
         12.4.2.2 Small Bore Piping Screening Guidelines
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13. INSTALLATION AND COMMISSIONING
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   13.6 Commissioning

14. OPERATING AND MAINTENANCE CONSIDERATIONS
ANNEX

Appendix 2.1 Schedule
Appendix 3.1 Preliminary Bottle Sizing Spreadsheet
Appendix 3.2 Bid Evaluation Spreadsheet
Appendix 6.1 Foundation and Skid Design Checklists
Appendix 7.1 Pulsation and Vibration Control (Dynamic Analysis) Checklists
Appendix 7.2A Information Required for Pulsation and Mechanical Vibration Analysis
Appendix 7.2B Information Required for Torsional Analysis
Appendix 7.2C Information Required for Thermal/Piping Flexibility Analysis
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.

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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

Lake Dallas
RPM: 1400, Pd: psig: 300.00

Driver: Caterpillar Model: G3520B
Frame: JT4D, MMSCFD: 1470 psia, 85.6°F
Thw1: 6.35ETU (6000) Stage: 1 Service: Service 1 SG: 0.6500, Suct Temp (F): 70.00
Thw2: 6.35ETU (6000) Stage: 1
Thw3: 6.35ETU (6000) Stage: 1
Thw4: 6.35ETU (6000) Stage: 1

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

GMC
Oct. 7, 2014
End User Perspective
What Works? Attention to Detail
End User Perspective
What Works? Attention to Detail

Size & Select Equipment
- Process requirements
- Value (hp/$, features/$)
- Operability
- Internal discussions
- Analysis
Spec / Bid / Purchase

- **Analyze**
  * Skid
  * Foundation & Soil
  * Acoustics
  * Piping (thermal, vibration, occasional)

- **Spec Creation**
  * lessons learned
  * internal discussions
  * details
Best Practices for Specifying & Procuring a Successful Large, Hi-Speed Reciprocating Compressor Package

End User Perspective

What Works? Attention to Detail

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
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.

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?

NODAL SOLUTION

STEP=1
SUB =6
FREQ=136.937
USUM (AVG)
RSYS=0
DMX =4.734
SMX =4.734
End User Perspective
What Doesn’t Work?

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

GMC
Oct. 7, 2014
End User Perspective

What Doesn’t Work?

Measured Engine Vibration Profiles at 1x
Fully Loaded at 1,000 rpm (highest 1x levels)

- 1x vibes (unit 9 pre-mods)
- 1x vibes (unit 9 post mods)

Improvement

Vibration (ips p-p)

Location (in)

- Near engine crankshaft level
- Engine foot
- Top of pedestal
- Lwr skid top
- Lwr skid bot
Best Practices for Specifying & Procuring a Successful Large, Hi-Speed Reciprocating Compressor Package

End User Perspective
What Doesn’t Work?
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.
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

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.
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.
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 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.

- 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.
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.
Fabricated skid mounted equipment has also shown demonstrated success in many applications including 8,500 horsepower reciprocating compression.
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
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.
As discussed earlier, small bore piping and instrumentation tend to manifest the ill effects of vibration. Small bore attachments require careful consideration.
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.
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.

There are of course some local customs or practices that aren’t anticipated but should be observed.
Compressor Considerations
Vent Gas Systems for Reciprocating Compressors
Section 9.13

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

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.
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.
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

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

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 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

Diagram of Waste Oil Tank, Packing Vent/Drain, Dist Piece Vent and Drain, and Drain.
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
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 selection can be affected by site conditions in two ways:

- **Intake air density too low**
- **Intake air cooling insufficient**
Engine selection can be affected by site conditions in two ways:

- Intake air density too low
- Intake air cooling insufficient
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

Air in

Fuel in
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

Diagram shows normal combustion on the left and detonation on the right.
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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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

**CAUTION**

**HYDROGEN SULFIDE**

**GAS MAY BE PRESENT**
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.
Engine mounts must be:

- Designed to be robust
- Installed/adjusted properly
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.
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 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
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 where 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
• **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**
• **Specification**
  - 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
• **Miscellaneous**
  • 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 for Specifying & Procuring a Successful Large, Hi-Speed Reciprocating Compressor Package

Packager Perspective

- **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
System Design Consideration and Best Practices

Kelly Eberle, Beta Machinery Analysis
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
System Design Considerations
Project Management and Planning - Scope

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.

System Design Considerations
Project Management and Planning - Timing

Vibration & System Analysis
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
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)
I. Overview
1. Overview

System Design Considerations
Best Practice Considerations

System Pressure Drop
2. Initial Activities (7.3)

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

**System Design Considerations**

**Best Practice Considerations**

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

Increased # of Load Steps and Ps Range
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

<table>
<thead>
<tr>
<th>ITEM</th>
<th>DESCRIPTION</th>
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<th>DESCRIPTION</th>
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</thead>
<tbody>
<tr>
<td>A</td>
<td>3/8&quot; thick gusset, min 1&quot; wide (2 req'd) * Alternatives to gussets on nozzles include using</td>
<td>B</td>
<td>Minimum 1/2&quot; distance between gusset and – Long weld neck flanges</td>
</tr>
<tr>
<td>C</td>
<td>3/8&quot; reapad * Always minimize the cantilevered weight</td>
<td>D</td>
<td>Stress relieve after welding reapad and gussets supported by small nozzles</td>
</tr>
<tr>
<td>E</td>
<td>Do not weld gussets to pipe or vessel shelf</td>
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</table>

**Notes:**
1. Width on small bore piping band clamp can be adjusted so it just covers both flanges.
2. Field welding may be required to ensure good fit-up
3. Avoid pipe strain when bolting up support.
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

**System Design Considerations**

- Mechanical (stiff) vs Thermal (flexible)

**Braces needed for vibration control**

High Stress due to Thermal Expansion
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

Shaking Forces > 3 times guideline
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
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**

![Graph showing vibration data with peak at 130 Hz]

3.0 ips pk @ 130 Hz
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)**

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

<table>
<thead>
<tr>
<th>Appendix 2.1: Recommended Project Sequence of Critical Events (p. 2/2)</th>
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<td><strong>Package &amp; Contractor Selections</strong></td>
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<tr>
<td>6.0</td>
</tr>
<tr>
<td>6.1 Select package and issue PO with complete scope &amp; all supporting specifications</td>
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<tr>
<td>6.2 Order driver and compressor (by package or occasionally other)</td>
</tr>
<tr>
<td>6.3 Select plant/building engineering consultant</td>
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<tr>
<td>6.4 Select building contractor</td>
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<tr>
<td><strong>System Design</strong></td>
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<tr>
<td>7.0</td>
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<tr>
<td>7.1 Reconfirm operating conditions</td>
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<tr>
<td>7.2 Size and order coolers</td>
</tr>
<tr>
<td>7.3 Finalize unloading scheme and control requirements</td>
</tr>
<tr>
<td>7.4 Complete torsional analysis</td>
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<tr>
<td>7.5 Complete package &amp; skid design layout for review</td>
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<tr>
<td>7.6 Complete preliminary plant piping layout</td>
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<tr>
<td>7.7 Finalize pulsation bottle sizing</td>
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<tr>
<td>7.8 Review equipment accessibility**</td>
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<tr>
<td>7.9 Complete pulsation study, mechanical analyses, skid dynamics analysis</td>
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<tr>
<td>7.9 Review pulsation/vibration study and affects on system performance**</td>
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<tr>
<td>7.10 Complete piping flexibility analysis</td>
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<tr>
<td>7.11 Complete building layout, stairs, platforms, crane access, etc.</td>
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<tr>
<td>7.12 Complete final plant design</td>
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<tr>
<td>7.13 Update off-skid pulsation and piping analysis with final design details</td>
</tr>
<tr>
<td><strong>Fabrication/Construction</strong></td>
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<tr>
<td>8.0</td>
</tr>
<tr>
<td>8.1 Fabricate package</td>
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<tr>
<td>8.2 Inspect package and conduct small bore piping MNF testing</td>
</tr>
<tr>
<td>8.3 Package control system and sequencing testing</td>
</tr>
<tr>
<td>8.4 Test package</td>
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<tr>
<td>8.5 Install foundation</td>
</tr>
<tr>
<td>8.6 Fabricate building</td>
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<tr>
<td>8.7 Install package</td>
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<tr>
<td>8.8 Complete process and utility piping</td>
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<tr>
<td>8.9 Align package</td>
</tr>
<tr>
<td><strong>Start-up &amp; Commissioning</strong></td>
</tr>
<tr>
<td>9.0</td>
</tr>
<tr>
<td>9.1 Cleaning, flushing and preparation for start-up</td>
</tr>
<tr>
<td>9.2 Final inspection &amp; checklist completion prior to start-up</td>
</tr>
<tr>
<td>9.3 Conduct initial vibration screening &amp; remediation if necessary</td>
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<tr>
<td>9.4 Torsional Testing</td>
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<td>9.5 Performance Testing</td>
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** Consider any trade-offs before plant construction & completion of package fabrication.
(pre-RFQ) Preliminary Bottle Sizing Tool

**Summary & Wrap-Up**

Preliminary Bottle Sizing for High Speed Compressor Packages in Natural Gas Transmission 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-E (a)*
### **Compression Bid Tab (EXAMPLE ONLY)**

<table>
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<tr>
<th>Item</th>
<th>Vendor A</th>
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<th>Vendor B</th>
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<td><strong>Bid-Evaluation Spreadsheet Tool</strong></td>
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**Summary & Wrap-Up**
## Bid-Evaluation Spreadsheet Tool (continued)

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**Technical notes:**
- List specific experiences from a technical perspective, feedback, quality/quantity of work
- Took exception to entire Company Purchase Spec
- Quote line was not identical to other equipment listed in RFB

**Subtotal:**
- Lowest: 600
- 555
- 575

<table>
<thead>
<tr>
<th>Option</th>
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<tr>
<td>Option 1: FOB Shipping to Site</td>
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<td>Option 2: Start up Assistance</td>
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<td>Option 3: 100% X-Ray on Vessels</td>
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<td>Option 4: PWHT on Bottles</td>
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<td>Option 5: Witness Run Test</td>
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<td>Option 6: 1/8&quot; Corrosion Allowance on Cooler</td>
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<td>Option 7: Two Scrubbers in line of one</td>
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<td>Option 8: Ship Board Style Cable</td>
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<td>597</td>
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</table>

**Commercial notes:**
- List specific experiences from a commercial perspective, feedback, accuracy of bids, size/frequency of ECR's
- After checking this was concluded stated in phone conversation that price to comply with Company spec was $20,000
-提 & C's to be negotiated with contract coordinator. Negotiated terms less than 1 year ago, process now expected to be more efficient.

**Subtotal:**
- Lowest: 600
- 422
- 564

**General notes:**
- Provided bid 1 week past deadline
- Attention to detail, communication was severely lacking
- Provided excellent support, customer service during bidding process
- Flexible and responsive to Company requests.

**Total Score:**
- 0
- 20
- 26

**% of Perfect Score:**
- 100.0%
- 75.0%
- 96.0%

**Contact Information:**
- The Man Company Energy
  1234 Freeway, Suite 1000
  Financially Responsible, TX, 75421
  Phone: 123-456-7890
  Direct: 123-456-7890
  TheMan@Company.com

- Peasant Purchasing
  1234 Freeway, Suite 1000
  Bois Brulee, CA, 94221
  Phone: 123-456-7890
  Direct: 123-456-7890
  PeasantPurchasing@Company.com

- Peasant B
  1234 Freeway, Suite 1000
  Chapter 11, CA, 94221
  Phone: 123-456-7890
  Direct: 123-456-7890
  PeasantB@Company.com

**Notes:**
- 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 response to their previous bid.
- Indicates key parameter where may be a negotiation point.
- Vendor B stated weeks later, verbally, that could comply with most all of Company purchase spec for ~20% above their previous bid. Lower price would not have changed the outcome of the bid evaluation.
- Indicates key parameter where may be rejected based on non-compliance.
- Indicates key parameter where vendor may be rejected based on non-compliance.
GMRC Vibration Screening Tool - EFRC

EFRC Vibration Screening Guidelines for Reciprocating Compressor Packages, Converted to pPk OA

- Process Piping
- Pulsation Dampers
- Compressor Cylinder (rod)
- Compressor Cylinder (lateral)
- Compressor Frame (top)
- Foundation

Velocity, pseudo Peak OA (inches per second):

- Zone A (Good, Design)
- Zone B (Acceptable, Field)
- Zone C (Marginal, Correction)
- Zone D (Unacceptable, Shutdown)
This guideline for piping vibration is based on the lesser of the following limits:
• 10 mils pk-pk displacement
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

PRESENTER CONTACT INFORMATION

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