Acoustical and Mechanical Analysis Report

MLB ENGINEERS, INC.

Petroleum & Natural Gas Engineering

ACOUSTICAL/MECHANICAL PIPING ANALYSIS

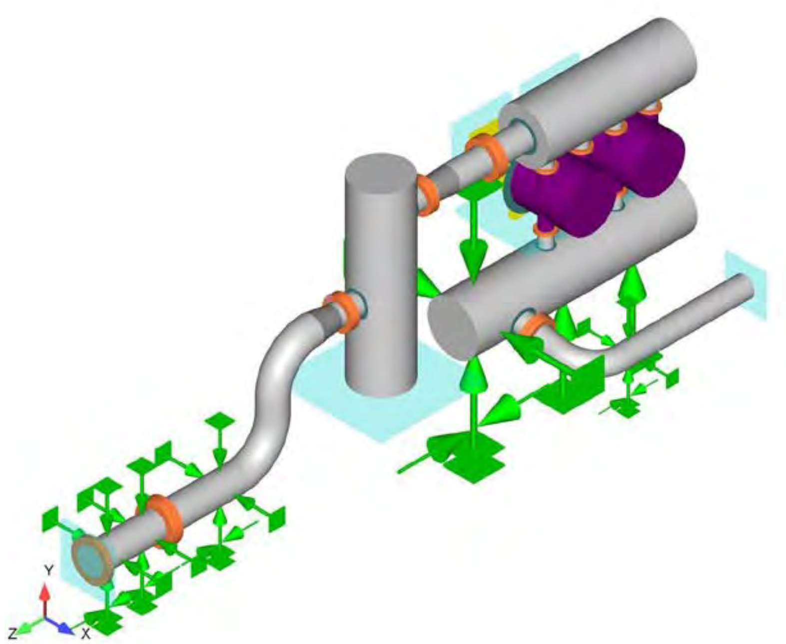
Technical Report 1354-01-18

XTO Energy
Poker Lake

Caterpillar G3616 A4 / Ariel KBZ/6 - 4 Stage

Packaged by:
Exterran Energy Solutions, L.P.

Unit Nos. US-123064 thru US-123072



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March 2018

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EXECUTIVE SUMMARY

A. INTRODUCTION AND SCOPE OF WORK

The compressor units under investigation are being packaged for XTO Energy by Exterran Energy Solutions, L.P. Acoustical and mechanical simulation software were used to predict pulsation amplitudes, shaking forces and mechanical natural frequencies, where applicable, for the compressor system(s) under investigation in accordance with the API 618 (5th Ed.) Design Approach 3 procedures. The mechanical analysis included a review of the piping configurations, the locations of piping supports, and the support types used from a pulsation-induced vibration and/or mechanically-induced standpoint.

Also included in the scope of the project was a piping restraint or thermal pipe stress analysis (API 618 Design Approach 3 (M.11). The objective of the analysis was to assess piping stresses and equipment loads during operating and environmental conditions.

B. ACOUSTICAL ANALYSIS

Based on the results of the acoustical/pulsation analysis, the following piping designs are proposed:

Stage	Mod/Rev	MLB Design Sketch No.
First Suction	1/5	13541S1
First Discharge	1/2	13541D1
Second Suction	1/4	13542S1
Second Discharge	1/2	13542D1
Third Suction	1/6	13543S1
Third Discharge	1/3	13543D1
Fourth Suction	1/4	13543S1
Fourth Discharge	1/2	13543D1

See Appendix A - Schematics for Acoustic Design Sketches and associated Standards.

See **Appendix B** for the predicted pulsation and acoustical shaking force results for the proposed piping systems. Sonic velocity (speed of sound) values of the process gas used for the acoustical filter calculations were per the Ariel compressor performance program (VMG gas model). A summary table for the speed of sound values used in the analysis can be found in Appendix A.

C. MECHANICAL ANALYSIS

Compressor Mechanical Analysis

The mechanical analysis of the cylinder manifold systems did not yield any calculated mechanical natural frequencies (MNF) below the recommended minimum frequency of 40 Hz for units typically operating at a maximum speed of 1000 RPM.

See **Appendix C** for the mechanical analysis and results. The model listing including the boundary conditions assumed for the major components, calculated MNFs and their associated mode shapes and potential coincidences with compressor operating speed frequencies can also be found in **Appendix C**.

Piping Supports and Pipe Stress Analysis

Support location and spacing for piping in close proximity to reciprocating equipment is based on nominal pipe size, length of pipe, relations to pipe bends and concentrated weights (valves). Piping should be supported as closely as possible to bends and concentrated weights. The **Maximum Clamp Spacing** chart can then be used as a guide to locate additional supports required based on the speed of the compressor(s). The natural frequency of piping spans near reciprocating equipment should be 2.4 times maximum rated speed. Clamp types in this service should be typical of the Type G (Guide) shown on drawing **STD009** and represented in drawings **STD010a** & **STD010b** or equivalent that provides lateral and vertical restraint and with minimal axial movement. Appropriately sized clamps based on the standard drawings (or equivalent) should be used in all locations unless noted otherwise or defined by thermal analysis.

In addition, valves and/or piping systems for relief, vent, drain, instrument, etc., configurations should be designed to be short and stiff and supported back to the major piping in at least two (2) directions. It should be noted that, even if the levels of the pulsation amplitudes/shaking forces for the piping system chosen for installation are below API 618 suggested guidelines, undesirable piping vibrations may be experienced if mechanical natural frequencies are excited. Piping configurations may also be excited into vibration due to residual crankshaft forces or couples corresponding to either the primary or secondary compressor order frequency or other external excitations.

Based on the mechanical piping restraint review process described above and the results for the thermal pipe stress analysis, several piping modifications (loops and offsets) and additional pipe supports were proposed in order to satisfy API 618 spacing guidelines based on mechanical natural frequency, API 661 nozzle load specifications for the coolers, to keep bottle nozzle stresses within ASME specifications, and to satisfy flange leak checks. Please see **Appendix D** for the complete results of this analysis. The details pertaining to the pipe support and layout recommendations can be found on the stress isometrics starting on page 352.

PROJECT SUMMARY

Compressor Unit(s) under investigation:	Natural gas engine driven, Ariel Model KBZ, six (6) throw, horizontally opposed compressor frames
Packager:	Exterran Energy Solutions, L.P.
Client:	XTO Energy
Number of units:	Nine (9)
Unit Numbers:	US-123064 thru US-123072
Number of stages:	Four (4)
Cylinders:	Two (2) 24.125(24-1/8Z:10) inch bore first stage compressor cylinders, two (2) 17.375(17-7/8Z:10) inch bore second stage compressor cylinder, one (1) 13.625(14-1/8Z:10) inch bore third stage compressor cylinder, and one 9.250(9-1/4ZK) inch bore fourth stage compressor cylinder
Inlet suction pressure range:	20 - 60 psig
Final discharge pressure range:	1000 - 1400 psig
Flow rate range:	16.149 - 28.726 MMSCFD
Design specific gravity:	0.70
Analysis conducted for:	Exterran Energy Solutions, L.P.
Data/Information supplied by:	Vishal Varia with Exterran

DESIGN APPROACH / OBJECTIVE

The major gas piping for the compressor unit(s) under investigation in this study was analyzed per MLB Engineers' Design IIIb calculation procedure [API Design Approach 3] to control pulsation-induced piping vibrations of the major gas piping systems. The study began by simulating the proposed suction and discharge piping systems. Next, various piping modifications were investigated, where required, to improve the overall acoustical mechanical characteristics of the piping systems.

The objective of the acoustical analysis is to determine a major gas piping design with characteristics that will attenuate the pulsation amplitudes generated by the reciprocating compressor cylinders rather than amplifying them. At the same time, the piping design is to consider the effects of pulsation levels on the compressor cylinder performance and the effects of pressure losses through the pulsation equipment on the horsepower/capacity values. The compressor cylinders and the major gas piping are to be simulated per MLB's Design IIIb calculation procedure which is consistent with the API 618 Design Approach 3 suggested procedure.

The objective of the mechanical analysis is to predict the major mechanical natural frequencies (MNF) of the compressor and piping systems. The MNFs are also compared to the frequency of predicted acoustical and mechanical forces in the systems. The intent is to avoid coincidences of these forces in order to minimize amplification of vibration amplitudes of critical or excitable MNFs by maintaining defined separation margins. If specified in the scope of work for the project, forced response analysis is performed determining dynamic stresses, vibration levels and stresses found on the pulsation suppression device internals. Also, the major mechanical natural frequencies of the piping configurations and pipe spans should not coincide with the remaining pulsation amplitudes which reduce the chances of experiencing gas pulsation induced piping/equipment vibrations when the unit(s) is (are) operating. The mechanical analysis procedure described above is consistent with the API 618 Design Approach 3 suggested procedure.

CALCULATION PROCEDURE

The acoustic analysis consists of simulating and predicting the pulsation levels in the on-skid piping. If available and included in the scope of the study, the off-skid piping including interstage piping and compressor inlet and outlet piping (station piping) are also modeled to a point where piping changes will have insignificant effects on the parts of the system under study (usually a large vessel upstream and downstream of the unit(s) under consideration). The mechanical analysis includes the cylinder-manifold systems, a review of the on-skid piping configurations (and off-skid piping as applicable), the locations of piping supports, and the support types used from a pulsation-induced vibration and/or mechanically-induced standpoint.

A. Pulsation Analysis /Control: The primary means used to control pulsation amplitudes for the referenced compressor unit are low pass acoustic wave filter systems (volume-choke-volume configurations). On suction, the inlet gas scrubber is used as the secondary (filter) volume; whereas on discharge, a combination surge/filter bottle is incorporated into the piping system.

- The surge chamber (volume) - interconnecting pipe (choke) - filter chamber (volume) comprise a low pass acoustic wave filter attenuating pulsation amplitudes in the downstream piping above its cut-off frequency at approximately twice the Helmholtz frequency.
- Resistive orifices are installed in the compressor cylinder flanges (nozzles) attenuating the higher frequency pulsation amplitudes primarily at the compressor cylinder valves by detuning / altering the acoustic resonance(s) of the gas passage-cylinder nozzle configuration. The decision to use either cylinder or line resistive orifices is always based on the attenuation of pulsation amplitudes versus the impact of the pressure drops (static and dynamic) on horsepower and capacity (BHP/MM) values.

B. Mechanical Analysis /Control: The primary objectives, considerations and assumptions of the mechanical analysis are:

- To determine the major mechanical natural frequencies of the cylinder manifold and piping systems. It is the intent, when possible, to maintain a minimum MNF of 2.4 times rated speed for any piping system in close proximity to the compressor, in particular, that they not coincide with the first (1X) or second (2X) compressor order frequencies since the excitation at these frequencies can be due to acoustical shaking forces, gas forces, and/or inertial forces and couples.
- To determine the major mechanical natural frequencies of critical compressor and piping systems, when applicable, such as how they relate with acoustical or mechanical excitation frequencies.
- To determine if support design and spacing adheres to API 618 recommended practices and guidelines. Recommendations made are based on pipe spacing charts and/or dynamic model results.

Support locations and spacing for on and off-skid piping close in proximity to reciprocating equipment are based on nominal pipe size, length of pipe, relations to pipe bends and concentrated weights (valves). From the acoustical/mechanical perspective, key considerations for piping layouts are to minimize the number of piping bends/turns and to maintain the piping at or below grade where it can best be supported. Bends in the piping represent energy transfer points that can increase the possibility of the occurrence of acoustical and/or mechanically induced vibration. This being the case, piping loops and elevated layouts should be avoided when possible. The **Maximum Clamp Spacing**[1] chart may then be used as a guide to locate additional supports required based on the speed of the compressor(s).

Per API guidelines, the natural frequency of piping spans near reciprocating equipment should be at least 20% above two times engine speed. Clamp types in this service should be typical of the **Type G (Guide)** shown on drawing **STD009** and represented in drawings **STD010a & STD010b** or equivalent that provide lateral and vertical restraint and with minimal axial movement. Appropriately sized clamps based on the standard drawings should be used in all the recommended locations unless noted otherwise or defined by thermal analysis. Discharge bottles beneath compressor cylinders should be supported with wedges and clamps or with an equivalent support to provide acoustical dampening and adjustment for thermal expansion (See **STD0017** & **STD0018**).

To help prevent mechanical excitation of suction scrubbers installed on compressor skids, the vessel skirts should be as stiff (short) as possible and mounted securely onto major skid beams; see **STD006** for more details. Special care should be taken to support the external choke tubes of acoustical filters since they are part of the acoustical dampener and may have relatively high pulsation levels. Suction bottles, particularly single cylinder systems, should have stiff (short) gusseted reinforced outlet nozzles (cylinder nozzles) or long weld neck (LWN) flanges with reinforcing pads. Support bracing for suction bottles and vertical scrubbers or filters may be required under special circumstances.

In addition, valves and/or piping systems for relief, vent, drain, instrument, etc., configurations should be designed to be short and stiff and supported back to the major piping in at least two (2) directions. It should be noted that, even if the levels of the pulsation amplitudes/shaking forces for the piping system chosen for installation are below API 618 suggested guidelines, undesirable piping vibrations may be experienced if mechanical natural frequencies are excited. Piping configurations may also be excited into vibration due to residual crankshaft forces or couples corresponding to either the primary or secondary compressor order frequency or other external excitations.

[1] Note that the spacing intervals specified on the Maximum Clamp Spacing Chart apply best to relatively long, straight runs of pipe, such as suction and discharge headers. For piping runs with bends and valve assemblies, etc., our experience indicates that more conservative (shorter) spacing intervals are required to maintain the mechanical natural frequencies at the recommended levels. In this case, spacing intervals 50-75% of the chart values may be required.

OPERATING CONDITIONS

The data contained in this report was recorded when the compressor unit(s) was simulated under the following operating conditions (flange pressures):

	Condition #1 Case #33	Condition #2 Case #36
First Suction Pressure, psia	72.131	72.131
First Suction Temperature, F	50	50
First Discharge Pressure, psia	179.661	170.931
First Discharge Temperature, F	193	192
First Stage HE-3 Clearance, %	30.870	UNL
First Stage HE-5 Clearance, %	UNL	UNL
First Stage CE Clearance, %	13.770	13.770
Second Suction Pressure, psia	175.471	166.371
Second Suction Temperature, F	130	130
Second Discharge Pressure, psia	417.121	362.881
Second Discharge Temperature, F	259	250
Second Stage HE Clearance, %	67.880	UNL
Second Stage CE Clearance, %	19.390	19.390
Third Suction Pressure, psia	409.011	353.301
Third Suction Temperature, F	130	130
Third Discharge Pressure, psia	754.061	764.171
Third Discharge Temperature, F	228	249
Third Stage HE Clearance, %	63.710	63.710
Third Stage CE Clearance, %	24.260	24.260
Fourth Suction Pressure, psia	738.361	744.021
Fourth Suction Temperature, F	130	130
Fourth Discharge Pressure, psia	1033.121	1441.121
Fourth Discharge Temperature, F	184	230
Fourth Stage HE Clearance, %	81.680	81.680
Fourth Stage CE Clearance, %	32.370	32.370
Capacity, mmscfd	28.738	20.666
Compressor Calculated Speed, rpm	1000	1000
Compressor Speed Range, rpm	750-1000	750-1000
Compressor Speed Range, rpm (data recorded)	675-1100	675-1100