Seal Oil Piping Vibration on an Oil Free Screw Compressor in an FPSO Application

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Abstract

A dry screw compressor skid was fabricated for offshore service that included oil buffered mechanical seals on the compressor. During shop testing, excessive seal oil piping vibration was observed that resulted in pipe component failures.

The oil system was designed to include a common lube and seal oil system with a pump design pressure of 590 psi. There were six oil control valves on the system, including a lube oil pressure control valve, one flow control valve on the inlet end of the compressor, another flow control valve on the discharge end, two differential pressure controllers to maintain differential pressure on the seals for each end of the compressor, as well as a back pressure control valve for the oil system.

Vibration and pressure pulsation measurements indicated that the response was at the pocket pass frequency of 206 Hz. The source was determined to be at the compressor. Arrangement of the control valves and control sensing lines were likely contributors to the severity of the response.

Modification to the seal oil system included addition of several volumes at strategic locations to change the acoustical characteristics of the oil system to reduce the shaking forces in the pipe system. These changes along with pipe support modifications and changes to the control valve sensing lines were successful at reducing the pipe pulsations and vibration response to acceptable levels.

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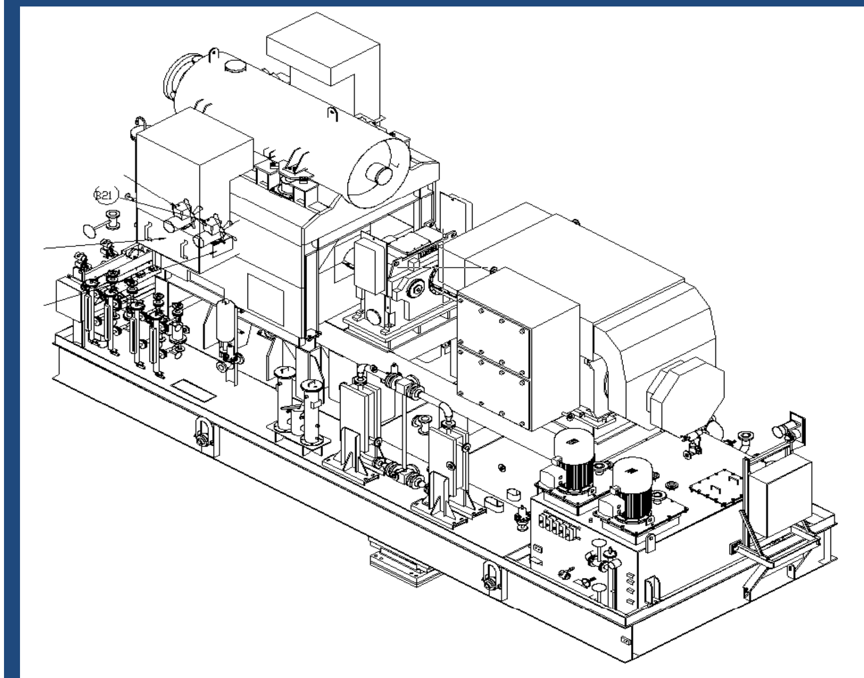
Equipment Description

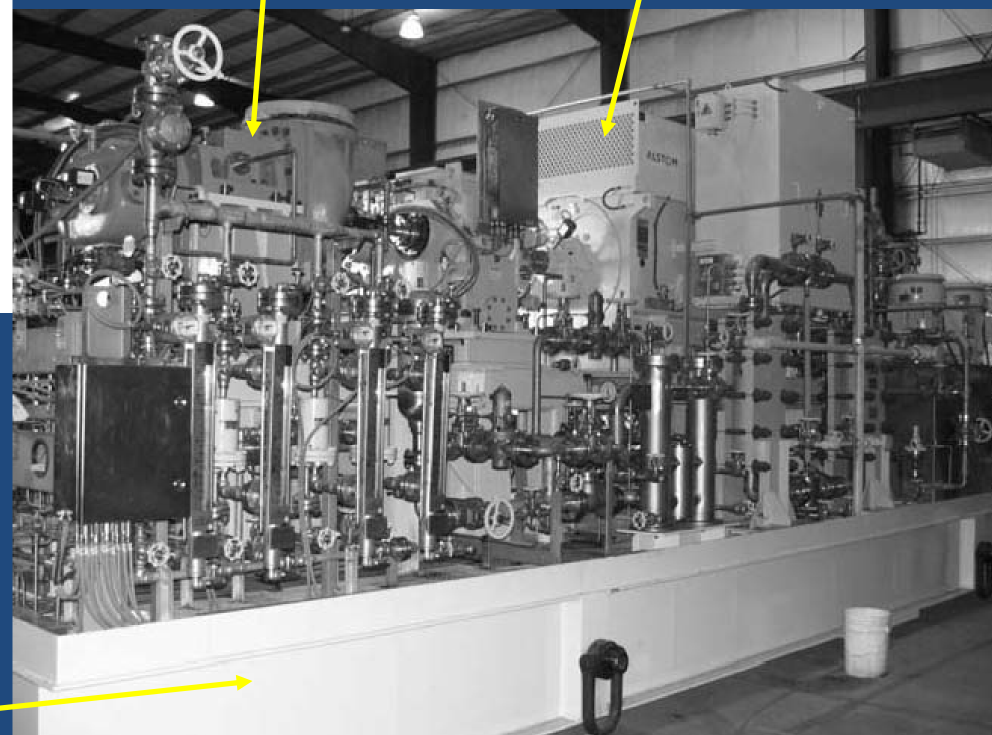
- Skid mounted Oil Free Screw Compressor with a combined lube and seal oil system.
  - Motor driven with gear increaser.
  - Oil buffered mechanical seals.
  - Very compact skid required for FPSO application including the entire machine train as well as the oil system.
  - Skid is point supported on 3 AVM's (anti-vibration mounts).

Compressor Details

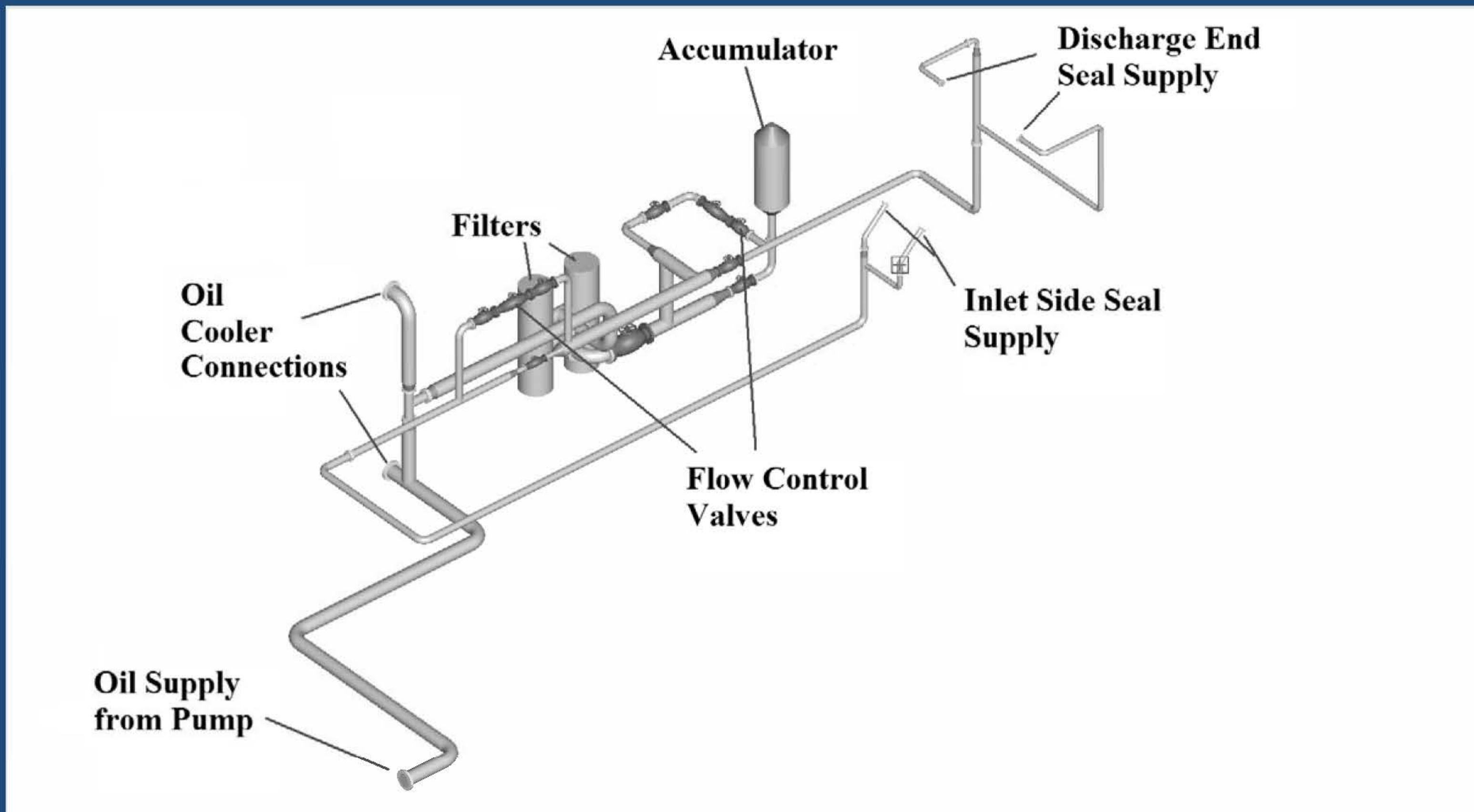
- 165S4 Oil Free (Dry) Screw Compressor
- 2950 HP 4 pole induction motor (50 Hz power)
- 2.13:1 gear increaser
- 3175 RPM Input Speed to Compressor
- 211.7 Hz Pocket Pass Frequency

General Skid Layout





Seal Oil Supply System



Vibration Test Results

- General piping vibration amplitudes were in the 0.2 – 1.0 in/sec peak range.
- Some locations on valves (handles, instrument connections, drains, etc.) were as high as 10 in/sec pk.
- Vibration was all at 206 Hz (1X pocket pass frequency).
- The entire skid had elevated vibration at 206 Hz.

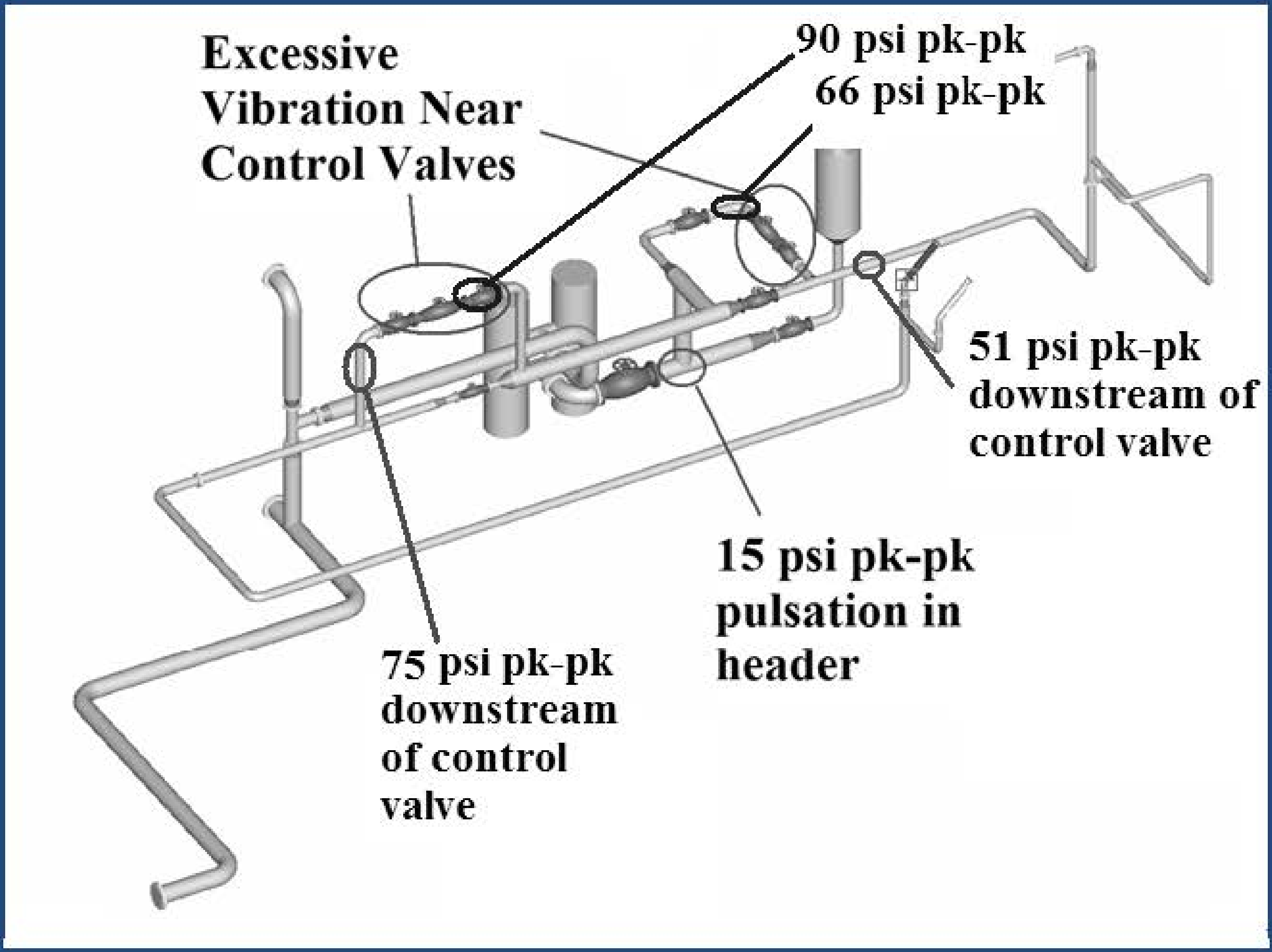
Initial Solution Path

- Investigate for piping system mechanical natural frequencies.
  - Numerous resonances near pocket pass frequency identified.

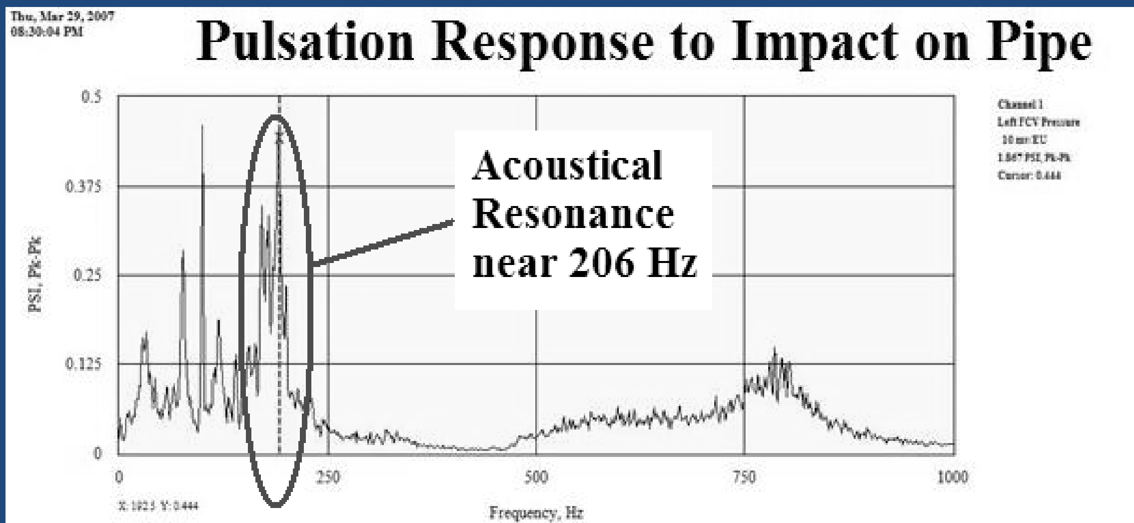
- Improve pipe system by adding additional pipe supports using elastomeric clamps.
  - Replaced a number of U-bolt clamps with lined clamshell type to improve rigidity and possibly add damping.

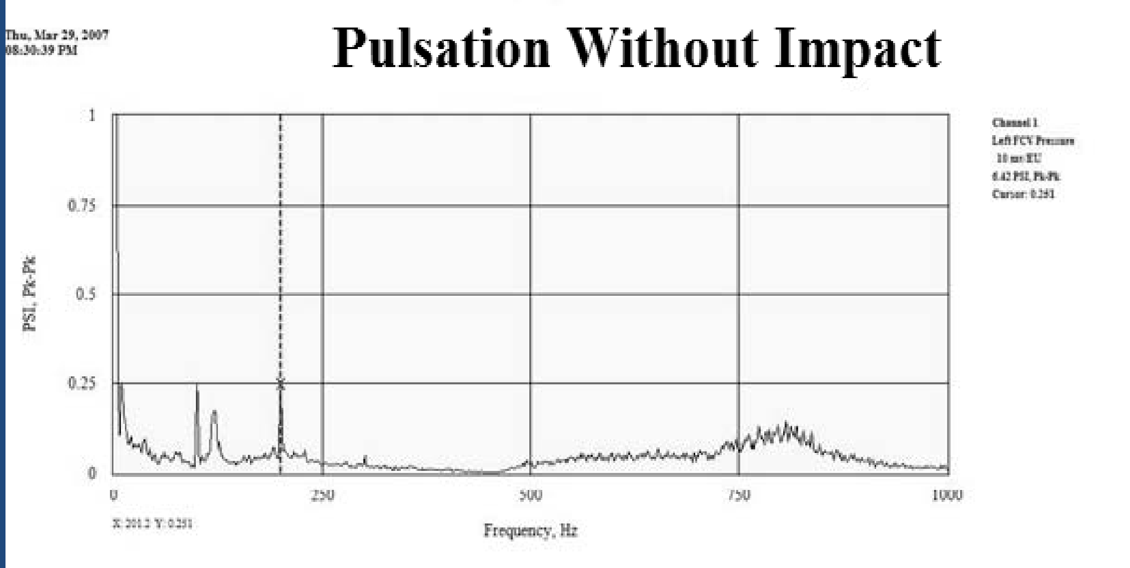
- Added hydraulic flex hose to each seal line to determine if the added compliance would reduce the forced response.
  - Some improvement but acceptable limits were not met.

Additional Test Results

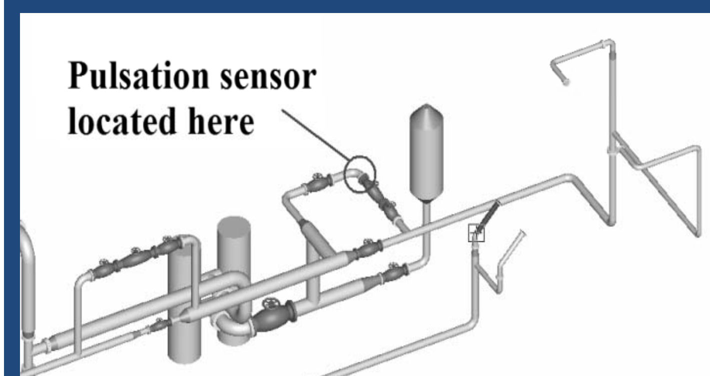


Test for Acoustical Resonance

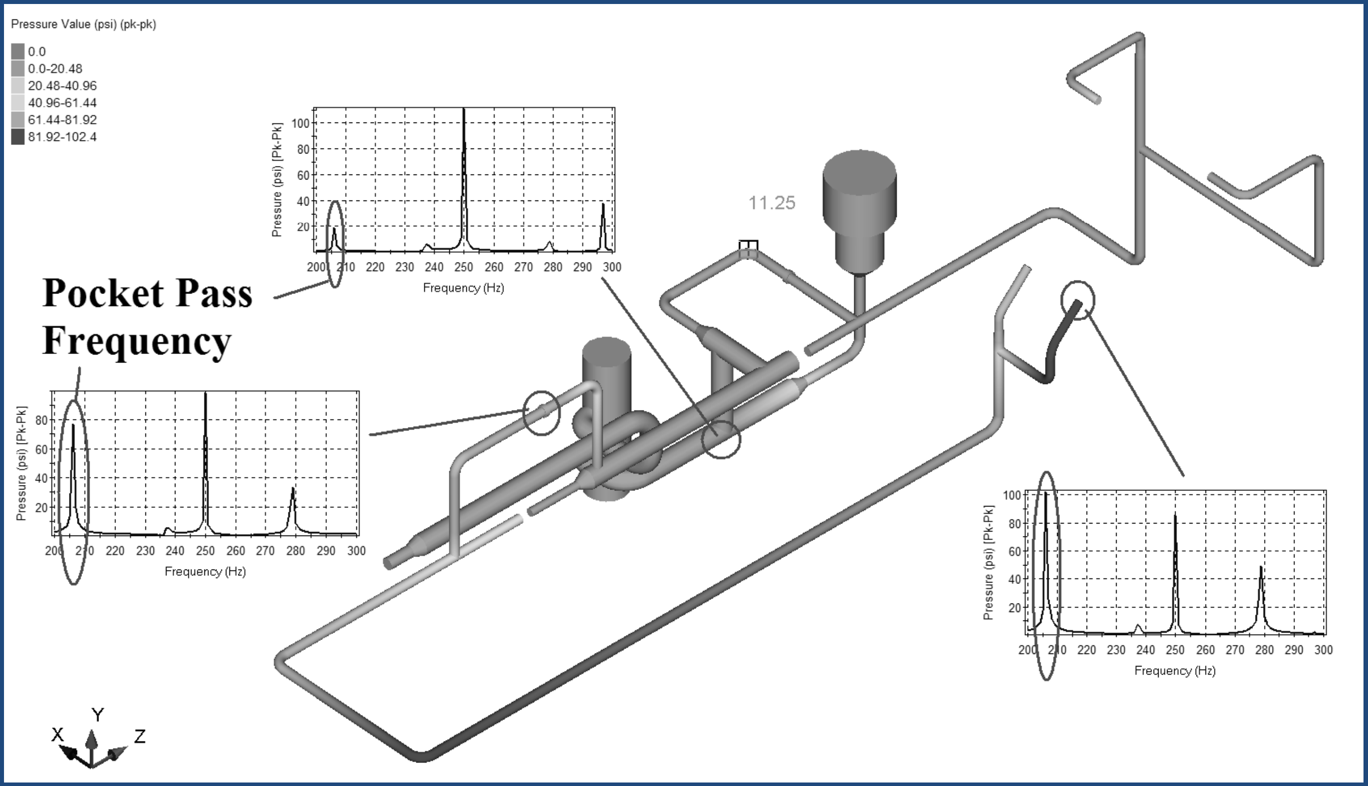




Pressure pulsation sensor installed near one flow control valve suggested that an acoustical resonance existed near 1X pocket pass frequency when pipe impacted with soft mallet.

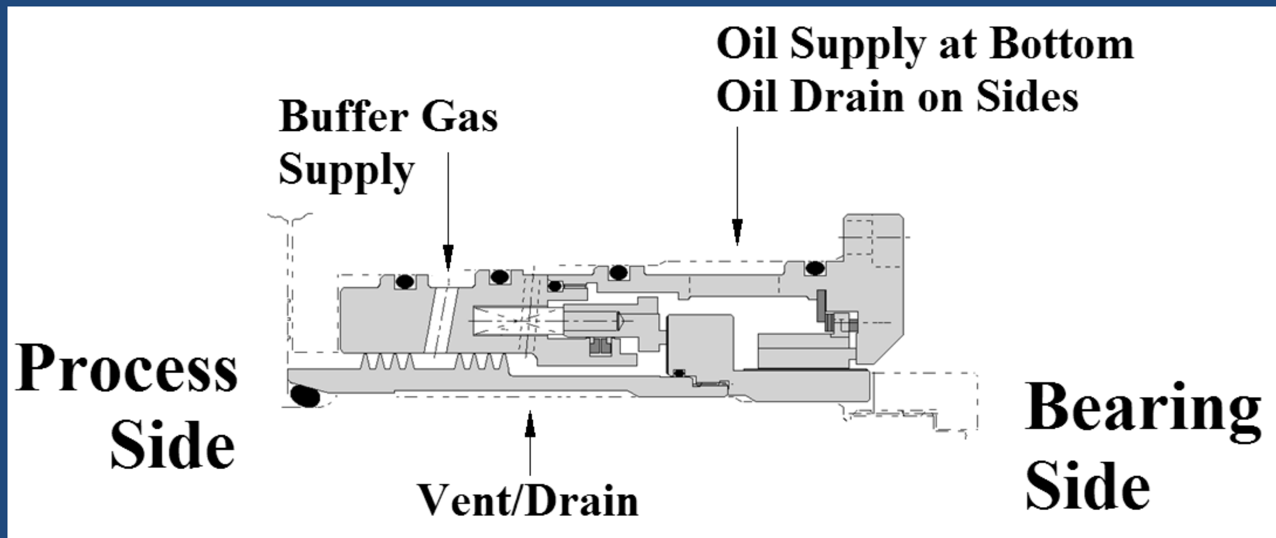


Acoustical Analysis



- Acoustical analysis of the seal oil supply and return piping was done using a pulsation source at the connections to the compressor with variable input frequency. An acoustical resonance was suspected in the system that was coincident with the pocket pass frequency of the compressor for the seal supply piping.

Seal Description



- The seals use were an oil buffered mechanical type. Seal oil was supplied to each seal assembly at approximately 30 PSI above reference gas pressure, using back pressure control valves.

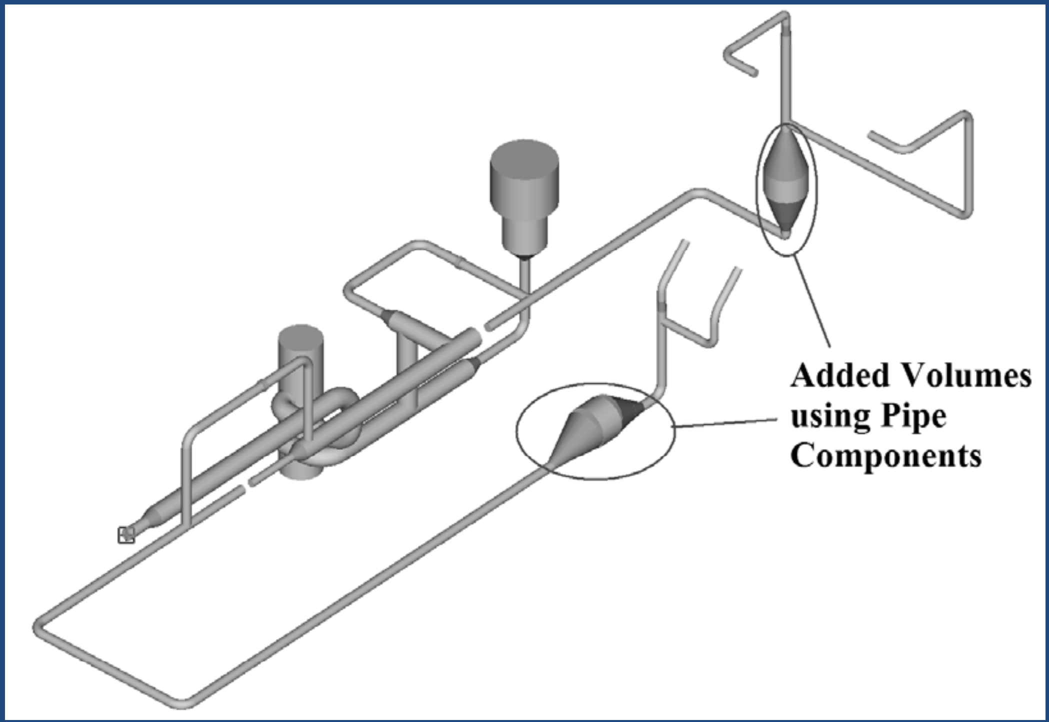
Possible Causes

- Control valves amplifying pulsations due to sense locations and number of valves in the system possibly cross talking.
  - Initial pulsation readings indicated pulsations were higher between the two flow control valves.

- Pulsation energy from the compressor feeding back in to the seal oil supply header.

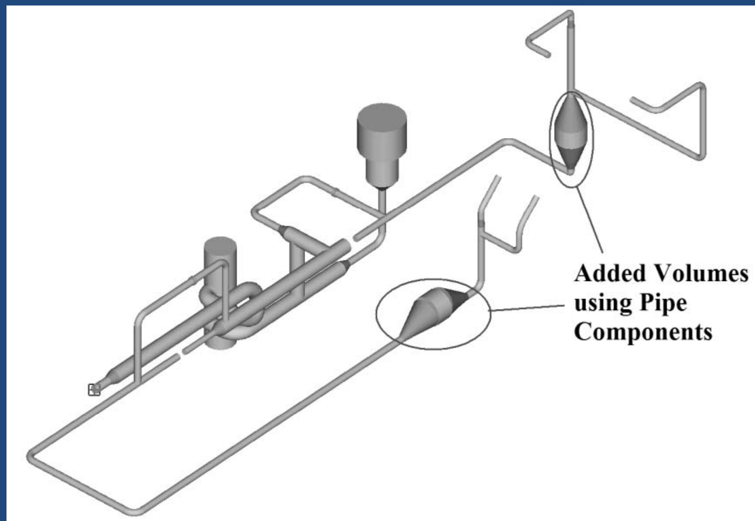
Final Solution

- Installed acoustical isolation volumes in the seal supply and return lines to de-tune acoustical resonance.



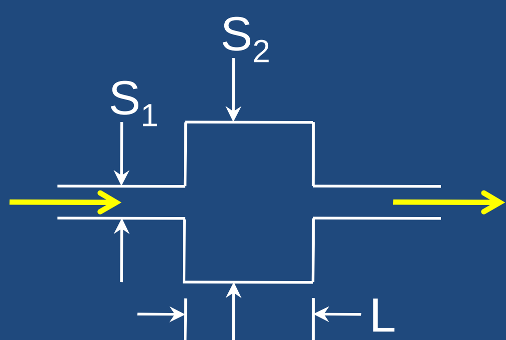
Similar volumes added to both the supply and return piping near the compressor.

Acoustical Volumes



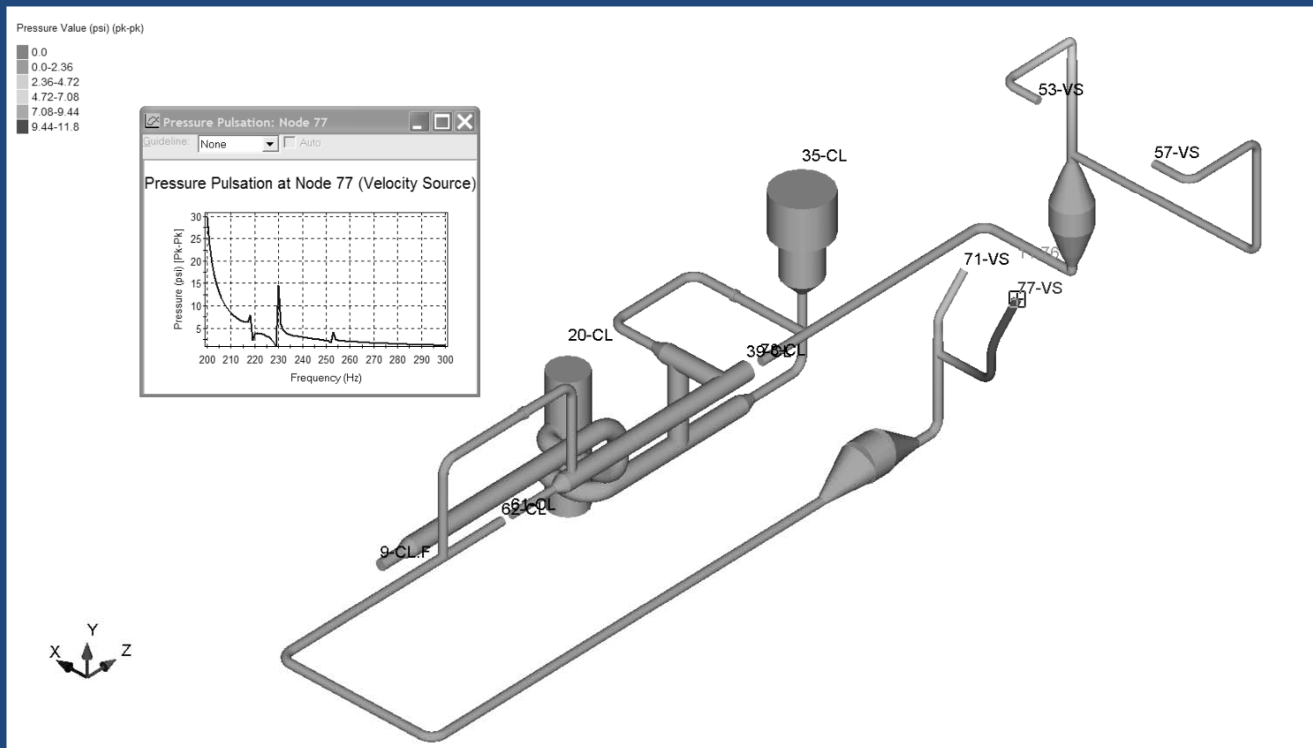
The size of the volumes was selected based on the concept that adding compliance would shift the natural frequency as well as provide some low pass filter effect.

The power transmission coefficient for the volumes selected was 0.1 at 206 Hz based on standard acoustical low pass filter theory (Kinsler, et. al.)



$$T_{\Pi} \approx \frac{1}{1+\left(\frac{S_2 - S_1}{2S_1} kL\right)^2}$$

Predicted Results with Volumes



- The predicted results were shown to almost eliminate pulsations upstream of the volumes as well as tremendously reducing the reaction at the seal connections at the compressor.

Final Test Summary

Location	Original	Hoses	Volume Prediction	Final Test
LP Supply downstream of FCV	75 psi pk-pk	40 psi pk-pk	1.0 psi pk-pk	1.2 psi pk-pk
LP Return upstream of BPV		5 psi pk-pk		0.02 psi pk-pk
HP Supply downstream of FCV	51 psi pk-pk	24 psi pk-pk	1.3 psi pk-pk	4.6 psi pk-pk
HP Return upstream of BPV		32 psi pk-pk		0.9 psi pk-pk
Seal Oil Header	13 psi pk-pk	11 psi pk-pk	0.5 psi pk-pk	1.5 psi pk-pk
LP upstream of FCV	90 psi pk-pk			
HP upstream of FCV	66 psi pk-pk			

- Pressure pulsation levels were significantly reduced along with corresponding vibration response.

Lessons Learned

- Acoustical response of seal oil piping can produce high pressure pulsations and vibration within seal oil supply system given the right conditions.
  - Previous systems of similar design did not have this problem.
  - Some axial shuttling of rotors is expected which may have produced pulsing flow at the seals.
  - The presence of multiple control valves may have contributed to the severity once the response started.
    - Inlet side flow control valves.
    - Outlet side back pressure control valves.
  - Acoustical resonance greatly amplified the pulsations.

Lessons Learned, cont.

- Correcting the acoustical forced response by adding volumes was much more effective than stiffening the pipe and/or de-tuning mechanical natural frequencies.
  - Although mechanical resonances were identified on the piping, correcting these alone by adding supports did not significantly reduce pipe vibration.
    - Many of the measured natural frequencies were not easy to calculate due to the relatively high frequency and complexity of the system, making them very difficult to predict.
    - Variation of valve brands (different hand wheel designs, etc.) changed the natural frequencies near 206 Hz.
  - The forced response from the pressure pulsations produced excessive vibration even when resonances were corrected.

Lessons Learned, cont.

- Pulsation levels were reduced by acoustical modification (added volumes) to reduce the forced response energy.
  - The pipe system response dropped dramatically once the pulsation energy was reduced in the piping.
- Future designs should consider review of the possible acoustical response of the seal oil piping.
  - Addition of pulsation damping hardware (compliant volumes and/or orifices) similar to concepts used for reciprocating pumps should be considered to reduce the potential for resonant response.