43rd Turbomachinery
30th Pump SYMPOSIA
GEORGE R. BROWN CONVENTION CENTER
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CO2 PIPELINE PUMP – PRESSURE PULSATIONS , VIBRATIONS, SEAL FAILURES – SOLUTION WITH THE HELP OF REMOTE MONITORING

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CO2 Pipeline Pump

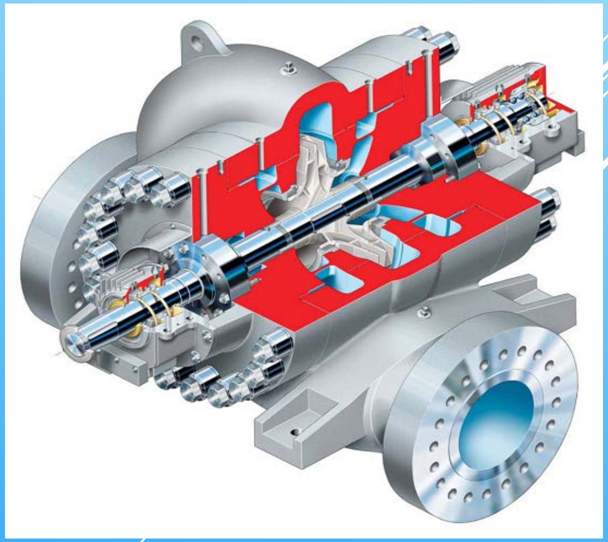
Dale Winterhoff:

- Technical Manager with a diverse background in a variety of disciplines that include 10 years in nuclear power generation, 15 years in petroleum refining, and 5 years in fine chemical production.
- Principal Engineer within the Flowserve Services and Solutions group. Concentrates in providing value to clients through comprehensive field reliability audits and by resolving critical and/or complex system problems requiring technically challenging field assessments.
- Has had a lead role in the development and application of companies wireless technology for pump monitoring.
- He holds a Bachelor of Science in Mechanical Engineering from the University of Illinois and specialized in direct energy conversion processes.

CO2 Pipeline Pump

Problem Statement

- First of four pumping stations carrying dense phase CO2 near critical point, from northern Colorado to west Texas for enhanced oil recovery (EOR)
- Inline16x16x26 DVS-RS, radial split, type BB2 (1500 psi drilled to 900 psi bolt circle), double volute, 7 vane impeller
- When running above 2000 rpm significant vane pass vibration was observed leading to seal failures and reduced pipeline availability
- Field testing did reveal abnormal pressure pulsations, >35psi, in the discharge pipe (next slide) and a high amplitude vane-pass vibration on the inboard bearing housing (next slide)
- The pulsation frequency is not linked to the running speed or a multiple of the running speed which indicates that the source of this excitation does not originate at the pump
- In addition, as the pumps speed was lowered, the pressure pulsation amplitude reduced as the energy of the pump reduced, however, the response frequency remained unchanged, ≈20,000 cpm (333Hz)



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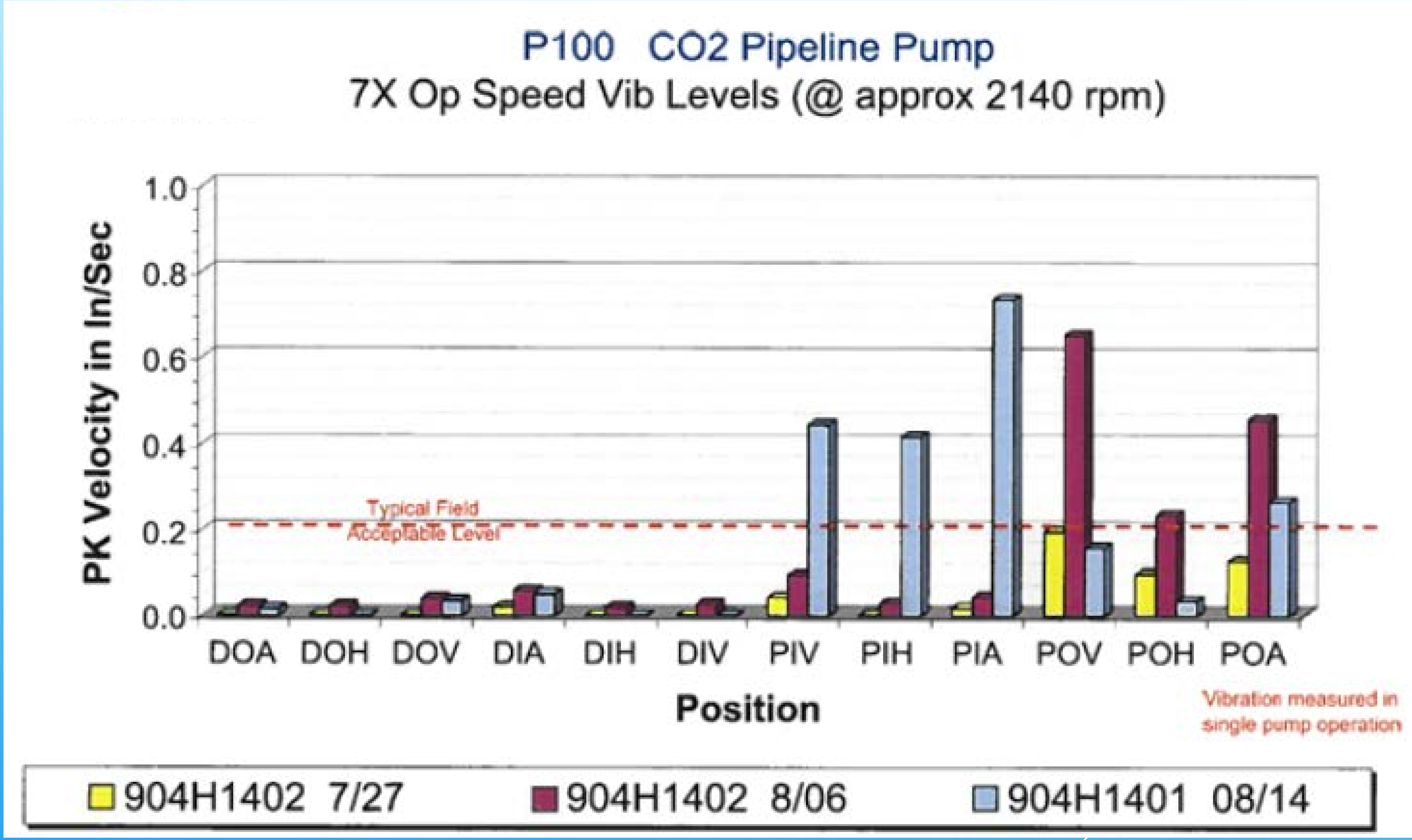

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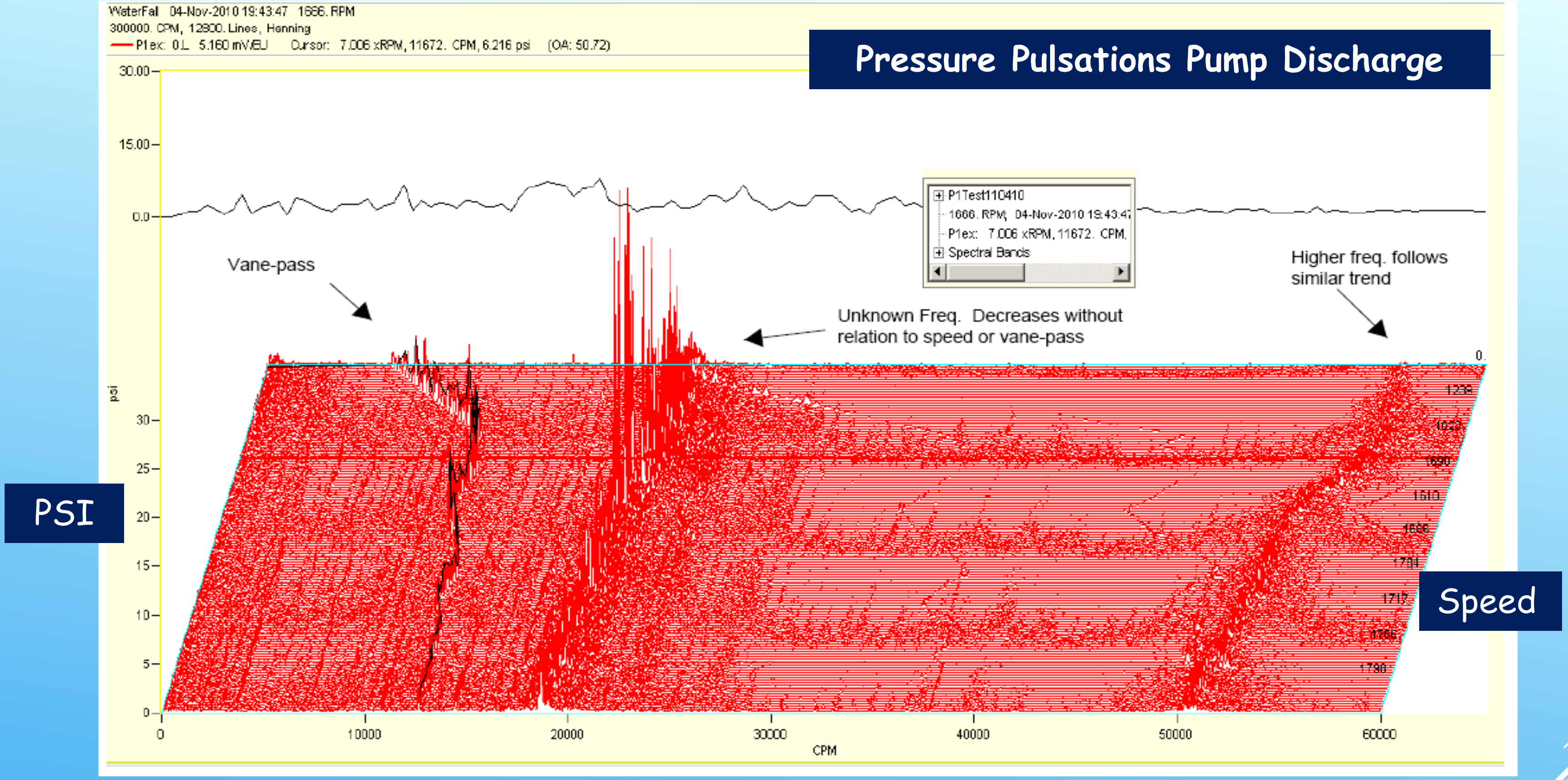

Since the pulsation frequency is not linked to the operating speed or blade passing excitation, we can conclude that this response is associated with an acoustic resonance in the pump or system. Possible correlation between product temperature and pulsation frequency was postulated but no conclusive data. Since the acoustic resonance in a mechanical system is dependent on the speed of sound in the liquid, the tests of the acoustic natural frequency would be expected to change with a change in temperature. Should the acoustic natural frequency drop onto the blade passing frequency, the amplification by blade passing forces would increase the pulsation amplitude significantly.

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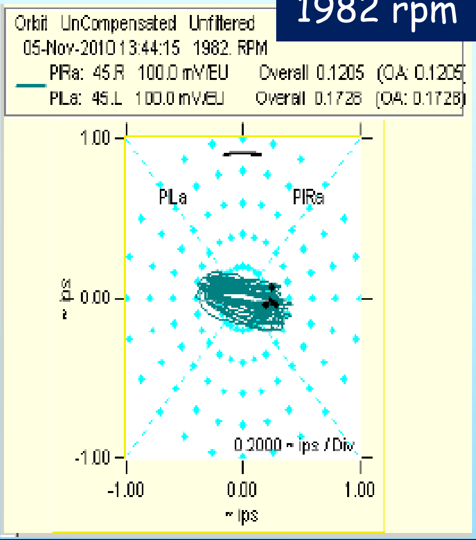
Initial Field Testing

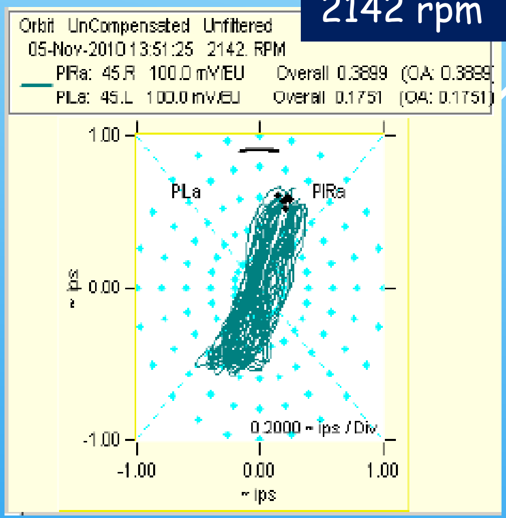
- Impact test of the bearing housings was performed and determined that a structural resonance is not likely causing high vibrations. The drive end bearing housing did not have any significant natural frequencies near the vane-pass frequency across the full operating range.
- The outboard bearing housing did however have a predominant natural frequency within the vane-pass frequency operating range, but was not excited during the operational tests. This natural frequency must be sufficiently damped minimizing the response when driven by low to moderate vane-pass excitation.
- All data was collected with traditional equipment and it was obvious that a long term monitoring solution was required that would not interrupt process, could capture transients and identify root factors, while allowing Operations to run with a normal line-up and satisfy production demands.

1982 rpm



Inboard Shaft Orbit
Phase change noted with small change in speed.

2142 rpm



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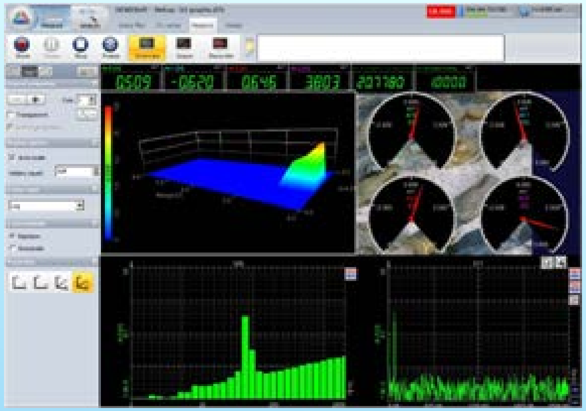
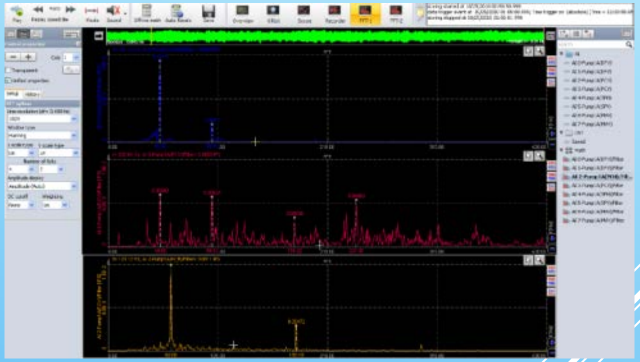
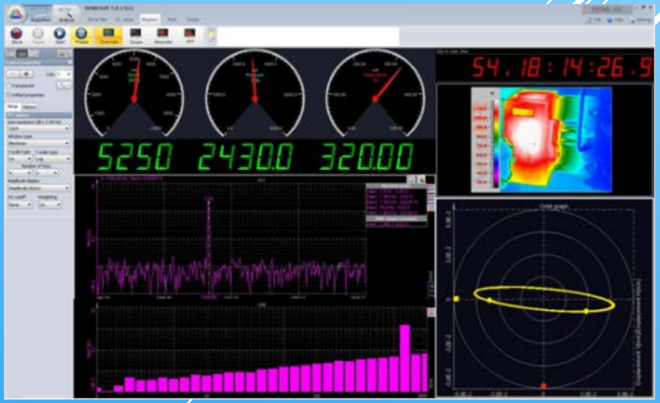
Remote Monitoring Platform

- Multi-channel, commercial of the shelf, data acquisition equipment configured for remote monitoring through a cellular connection allowed for live real time visualization and capture of data.
- Provided the ability for a focused data capture, either from a programmable event trigger and/or preset time interval
- Provided channel flexibility for application specific sensor configurations
- Alarm notification capability provided for timely actionable response to operational upsets
- Ability to share data, facilitated collaboration across technical teams
- Invaluable tool that can be used in solving difficult equipment issues







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Pump Monitoring Plan

- (5) Dynamic Pressure
  - Suction pipe near flange
  - Discharge pipe near flange
  - Seal Flush API 11 with inline filter
  - Inboard Stuffing box
  - Outboard Stuffing Box
- (2) Static Pressure
  - Suction pipe near flange
  - Discharge pipe near flange
- (2) Process Temperature RTD's
  - Suction
  - Discharge
- (1) Outside Air Temperature
- (5) Accelerometers
  - Inboard Bearing Housing X,Y
  - Outboard Bearing Housing X,Y & Z
- (1) Laser Speed Tachometer

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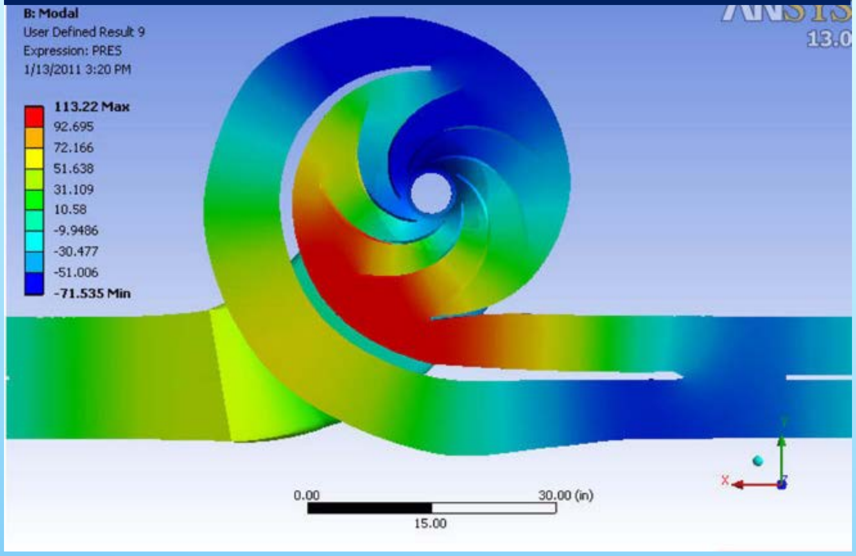
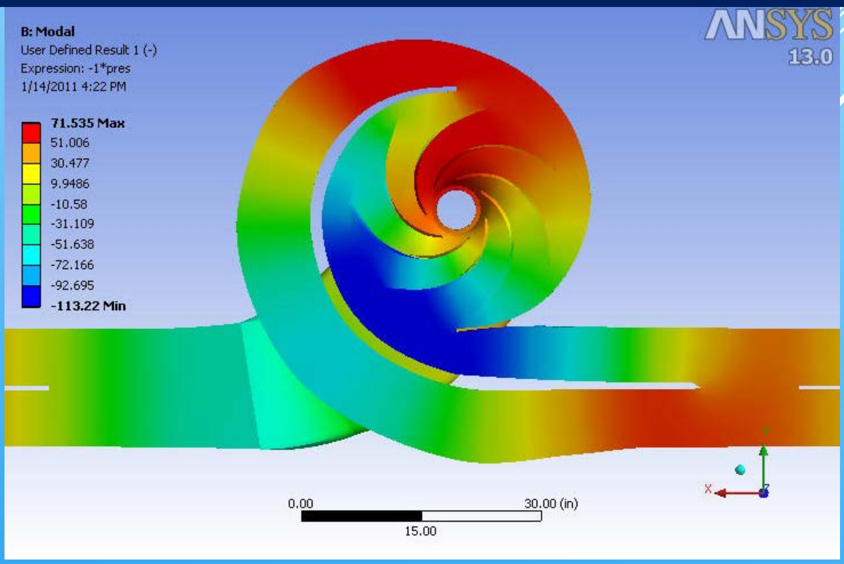
FEA Analysis

- 2-D Model was not the most accurate approach to evaluate piping concerns
- Needed to take the analysis a step further by creating a 3D model in a FEA software that deals with acoustic resonance
- Using FEA provided the ability to analyze specific frequencies more efficiently and accurately
- FEA Analysis concentrated on suction and discharge piping differences
  - Size of flanges with differences in ANSI pipe class
  - Location and length of splitters inside discharge piping was a large unknown
  - Orientation of piping
- Wet / Dry critical analysis was performed

FEA Forced Response Analysis @ 238 Hz



FEA Normal Response Analysis @ 238 Hz



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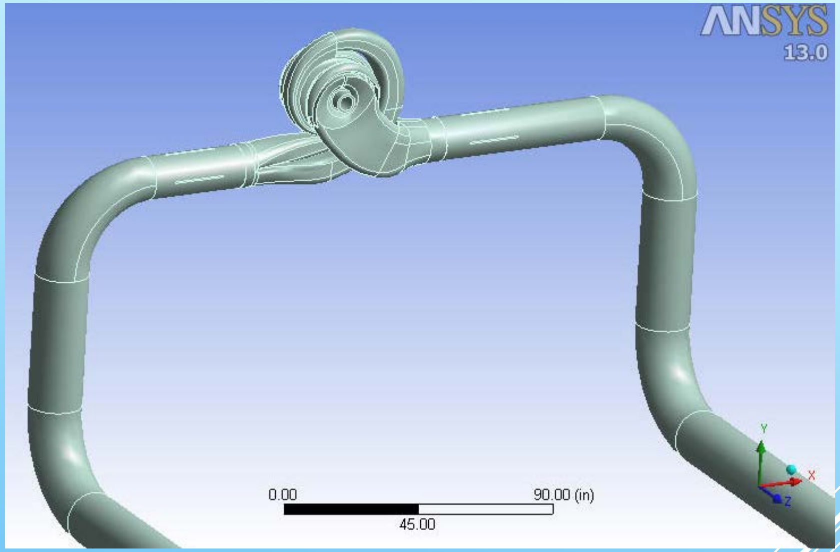
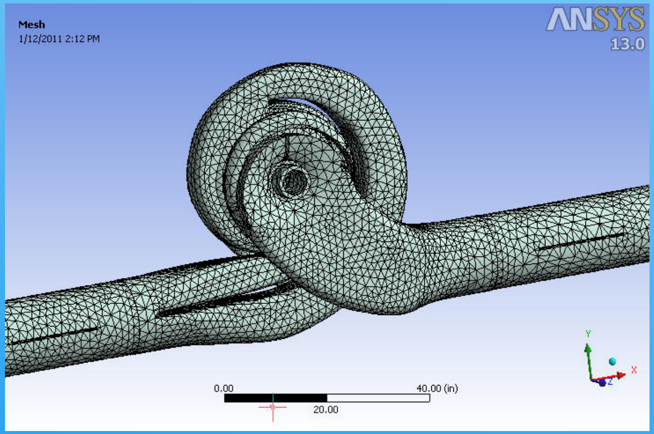
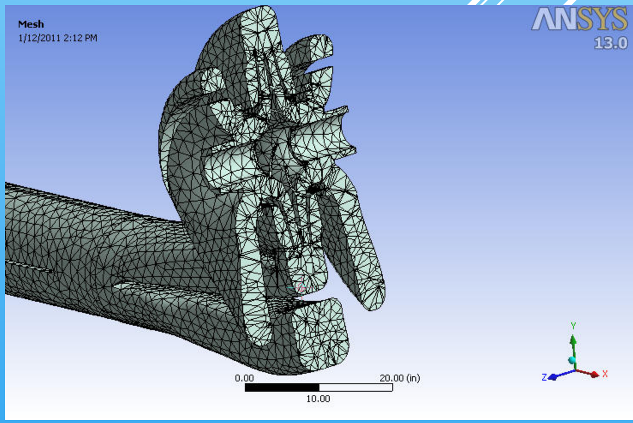
FEA Validation

- Since standard FEA only provides results every few Hz, iterative analysis using a Forced response separated out “possible” verses “most likely” scenarios
- By meshing the 3D model and inputting field data collected during operational evolutions we were able to achieve a higher degree of accuracy in our analysis simulations
- No structural or acoustic resonance issues were identified in the overall system
- Conclusion was that while these piping anomalies may contribute to shortened pump life they were not deemed as the root cause for the seal failures







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Data Analysis - Field Simulation

- Monitoring system allowed for a controlled test of the pipeline where the suction fluid temperature was raised above 100°F along with increasing pump speed above 2000 rpm.
- This simulated summertime conditions when process temperatures increased, Operations ran pump at higher speeds to compensate for the decrease mass of the CO_2 – result was increased pump vane pass frequency
- The speed of sound in CO_2 is directly related to the change in process temperature - result was that this temperature increase moved the non-driven frequency lower
- As the non-driven frequency and pump vane pass frequency approached each other, significant and destructive vibrations occurred - result was almost certain seal failure with any prolonged run time

Pump was administratively limited to operate below 2080 rpm when suction fluid temperature exceeded 98°F

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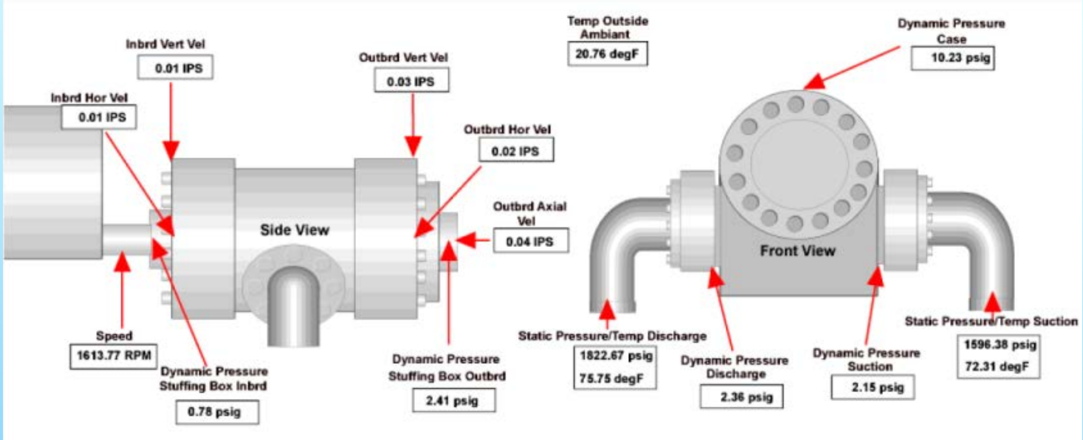
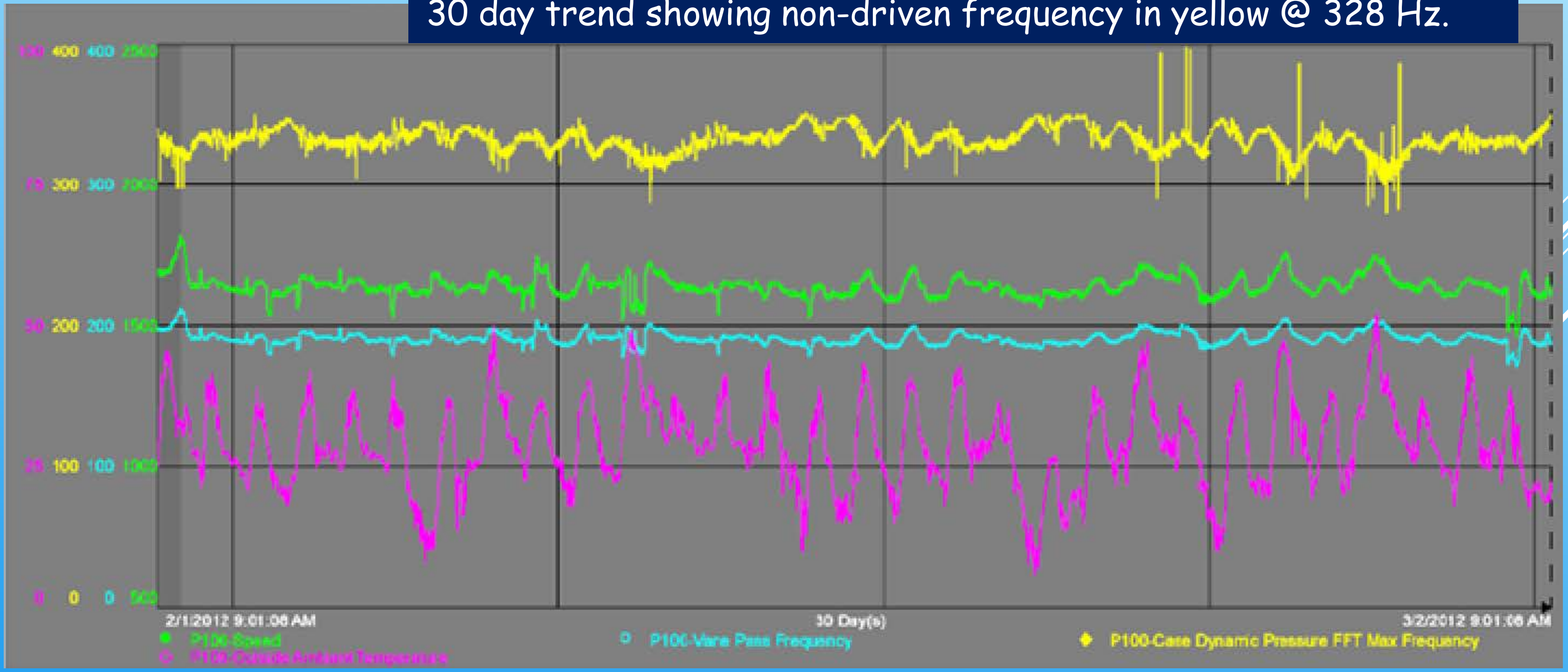
Pump Cold Conditions

- Pump speed average 1650 rpm with suction fluid temperatures below 72°F, 7 vane impeller.
- Note daily variance in outside air temperature, purple; vane pass, cyan with average @ 190Hz; pump speed green



30 day trend showing non-driven frequency in yellow @ 328 Hz.



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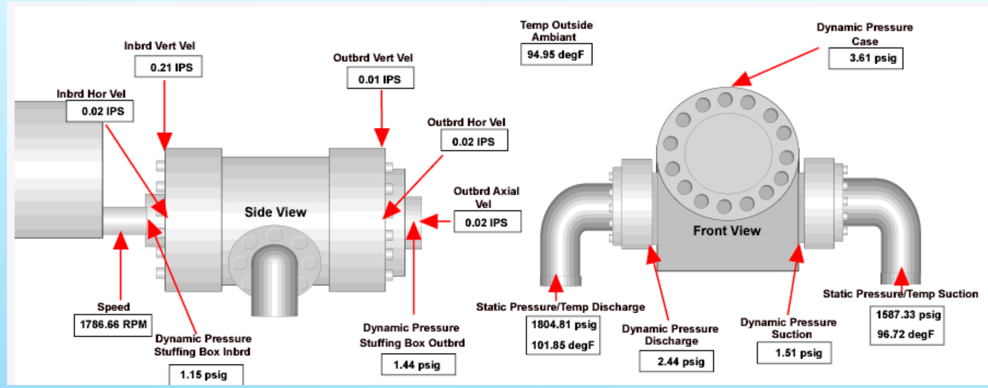
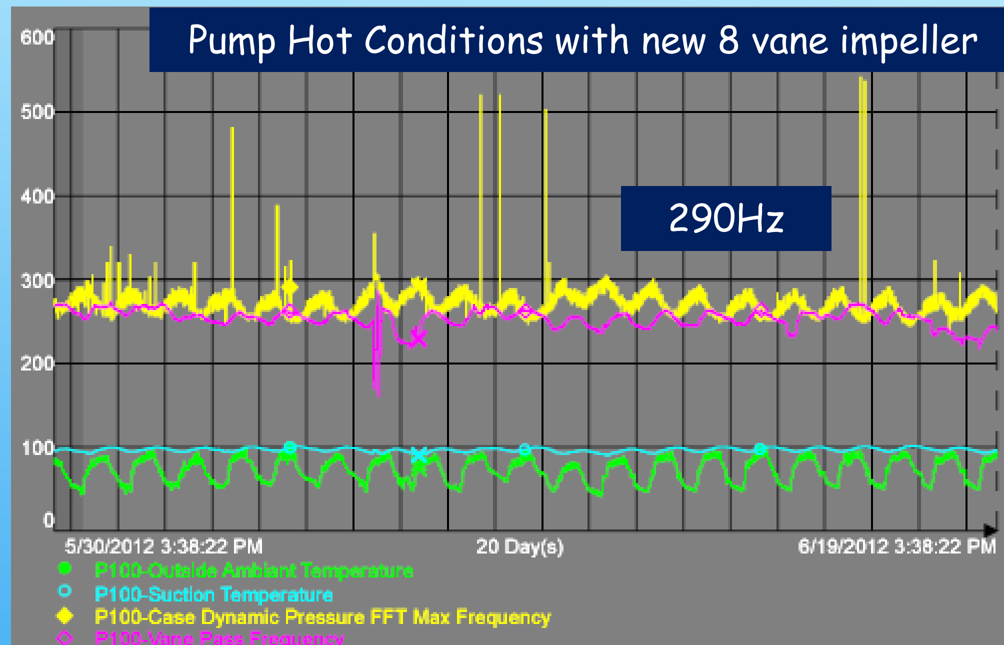
Root Cause & Solution

- Seals were failing due to amplification of the non-driven frequency dropping onto the blade passing frequency, at process temperatures above 98°F with pump speeds > 2080 rpm.
- Solution was an hydraulic rerate to 8 vane impeller, double volute - opposite conventional thinking
- Result was that the vane pass pulsation amplitude was 2 orders of magnitude reduced, (non detectable) allowing these two frequencies to overlap
- No vibration concerns observed at all speeds so that the speed restriction could be safely removed and operations could meet their production goals
- Secondary benefit of new hydraulic was more efficient design and lower HP (35 amps lower over all flow ranges)





20 day trend showing non-driven frequency in yellow overlapping with vane pass component in purple at elevated process temperatures (blue) and ambient temperatures (green) with high pump speeds >2080 rpm

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Conclusions

- Problem resolved by dramatically reducing pressure pulsation amplitude with new hydraulic design impeller.
- Remote monitoring was instrumental to characterize the field problem and provide insight for the hydraulic solutions.
- Monitoring system allows for different pump – system applications using specific sensor choices that can be easily deployed and moved. This can be configured with any combination of dynamic, analog or digital signals.