45TH TURBOMACHINERY & 32ND PUMP SYMPOSIA
HOUSTON, TEXAS | SEPTEMBER 12 – 15, 2016
GEORGE R. BROWN CONVENTION CENTER

Solving an Acoustic Resonance in Crude Oil Pump Internals

Southwest Research Institute®:
Francisco Fierro, Research Engineer
Sarah Simons, Research Scientist

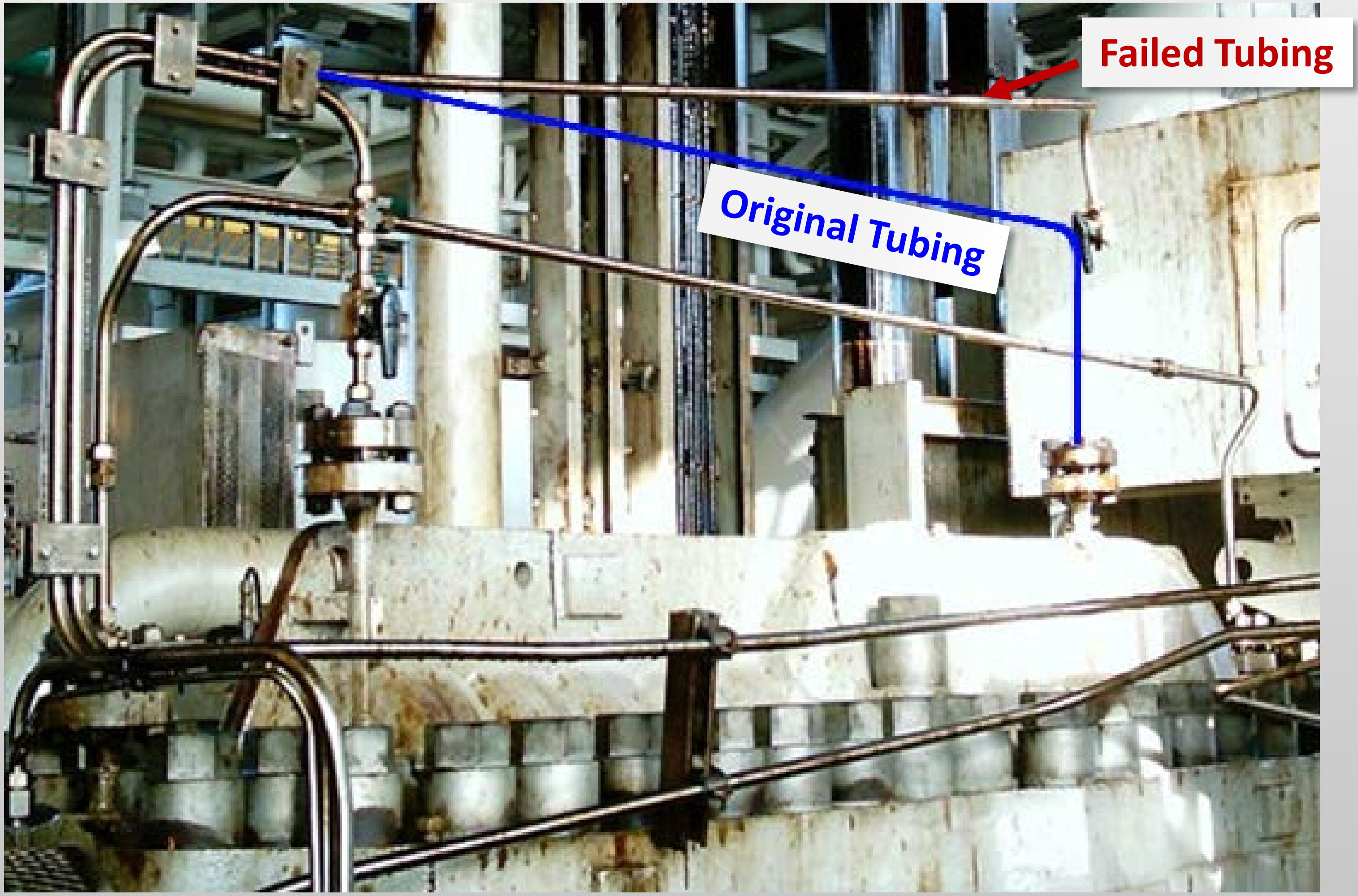
TEXAS A&M UNIVERSITY
TEES TURBOMACHINERY LABORATORY
TEXAS A&M ENGINEERING EXPERIMENT STATION

Speaker Biographies

- Francisco Fierro is a Research Engineer in the Fluids Machinery Systems Section at Southwest Research Institute. He performs mechanical system analyses to predict vibrational mode shapes and frequencies, vibration amplitudes, and related dynamic and thermal stresses. He also has field experience diagnosing and correcting vibration-related problems associated with various types of rotating machinery and piping systems.

- Sarah Simons is a Research Scientist in the Fluids Machinery Systems Section at Southwest Research Institute. In this position, she performs thermal and acoustic analyses of compressor and pump piping systems along with reciprocating compressor pulsation filter bottle design. She also leads projects in compressor and flow pulsation control research.

Case Study



Specific Problem

- Crude oil pump piping system that had previously operated without problems experienced a failure resulting in a release of oil
  - Vibration increased when a new well was opened and the fluid properties varied
  - Discharge piping connections had high vibrations—risk of failure
  - Tubing failure due to high vibrations in piping system transmitting through vent piping
  - Discrete excitation at 300 Hz

- SwRI performed field testing and in-house analysis to find the source and resolve the problem

Root Cause for Failure

- High forces due to acoustic resonance at 5× running speed, 300 Hz
- High cycle fatigue in threaded connection
- Original tubing un-available for test
  - Possible mechanical resonance, no data
  - Possible Excessive Flexibility
- Fatigue occurs in hours at this frequency. Because the acoustic natural frequency is not always tuned due to fluid property variation, e.g temperature, the vibration levels varied – and the tubing did not see the high vibration continuously.

<u>At 300 Hz</u>

1 million cycles in 3,333 seconds = 55 minutes

10 million cycles in 33,333 seconds = 555 minutes = 9 hours

Summary of Acoustic Behavior

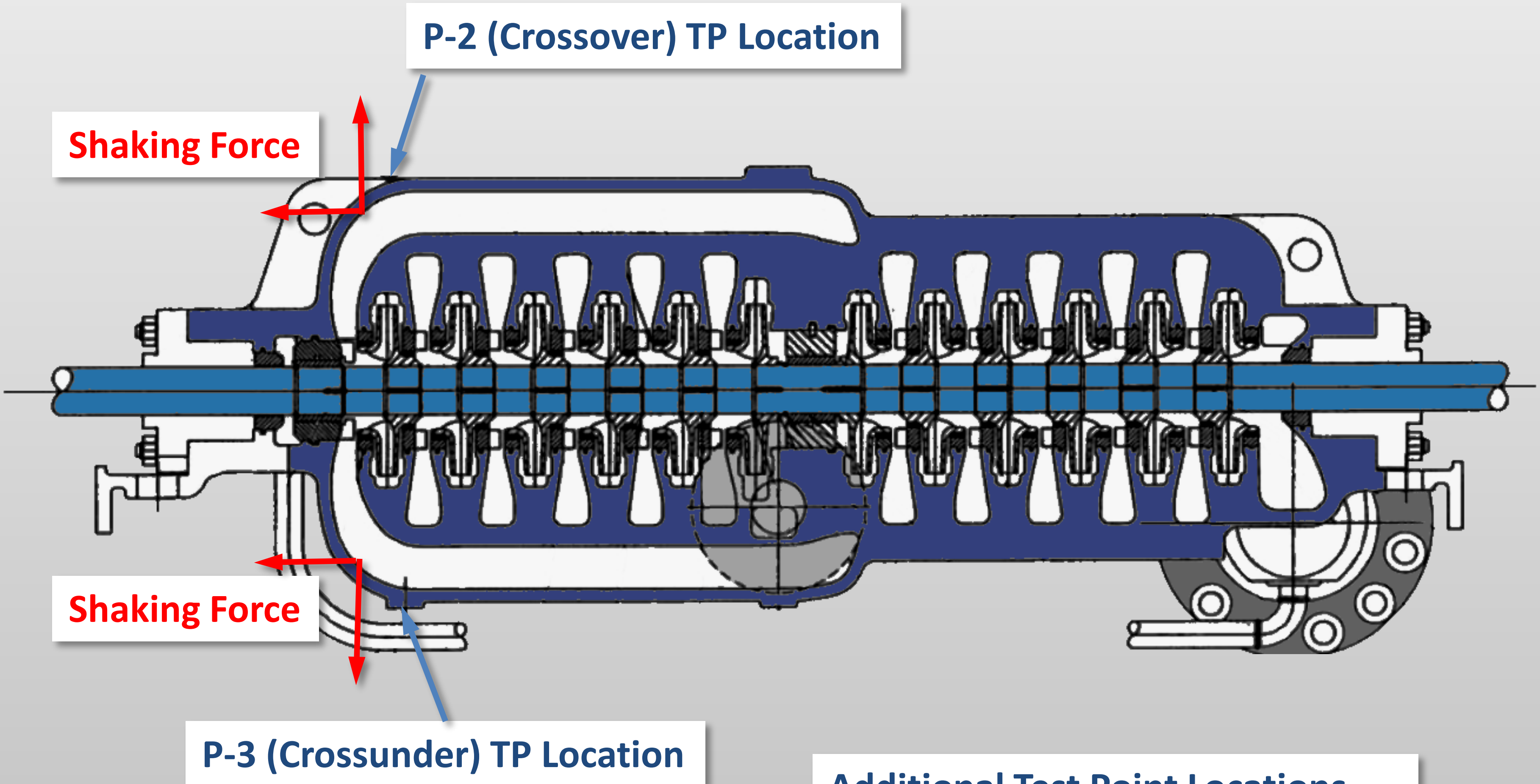
- Pulsation amplitude in the crossover varies significantly with fluid temperature.
- High crossover pulsation seen during startup.
- Pulsation amplitude varies from pump to pump and bearing housing vibration follows the pulsation amplitude.
- Crossover resonant frequency can be estimated based on fluid properties.

Pump System Description

Crude Oil Pump
Inlet Pressure: 50 psi
Outlet Pressure: 2700-3200 psi
Suction Temperature Range: 102-125 F
Running Speed: ~3600 rpm
Number of vanes per impeller: 5
Number of impellers: 12

Field Equipment
Pressure Transducer: PCB 112M66 In Line Charge Converter: PCB 422E52

Pump Internals and Test Point Locations



Additional Test Point Locations

P-1 (Suction Piping Connection)

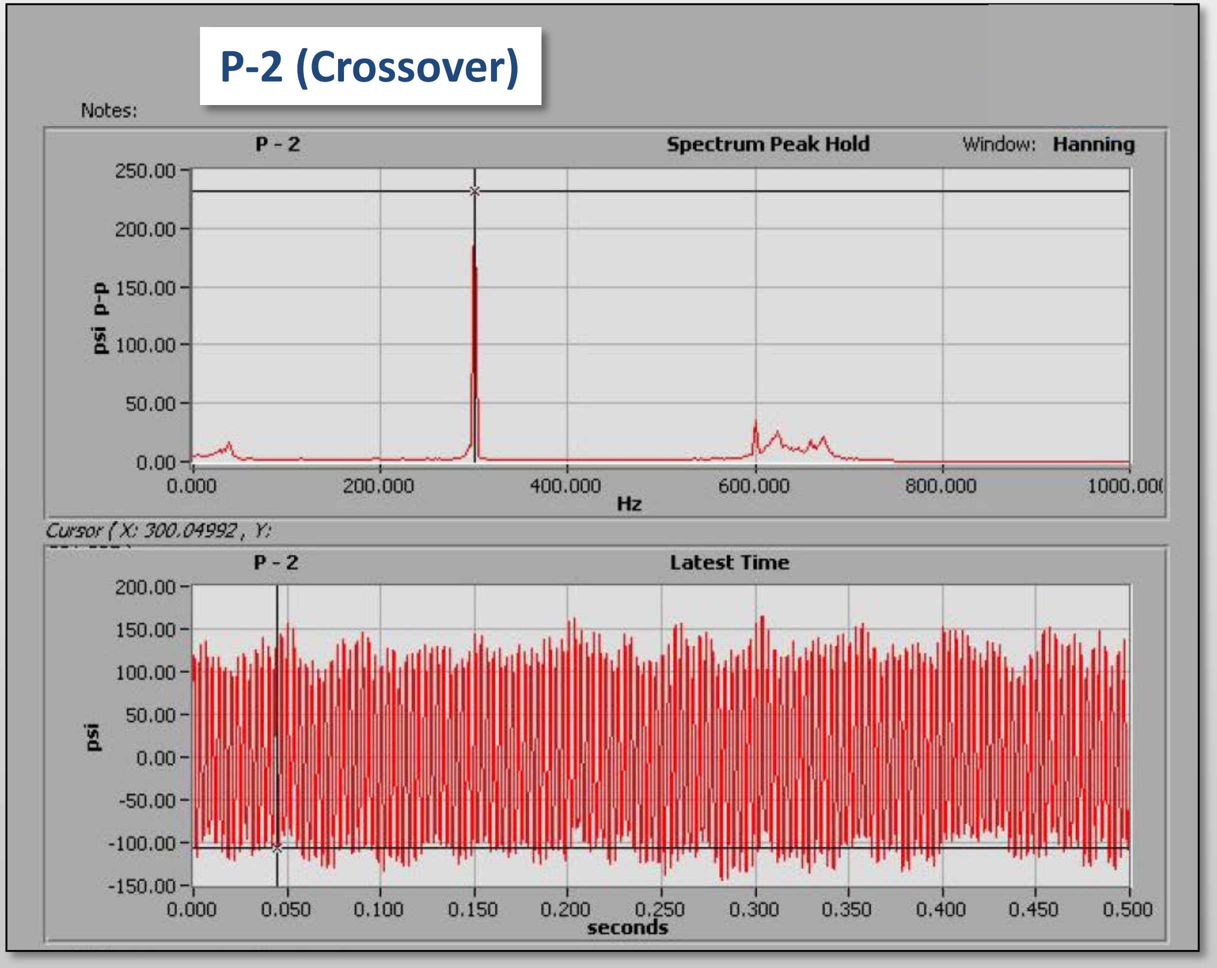
P-4 (Discharge Piping Connection)

PCB Dynamic Pressure Transducers

Pump System Dynamic Pressure Data

Pulsation Amplitudes at Start-up 112 deg F
P1: 20 psi p-p
P2: 556 psi p-p
P3: 575 psi p-p
P4: 40 psi p-p

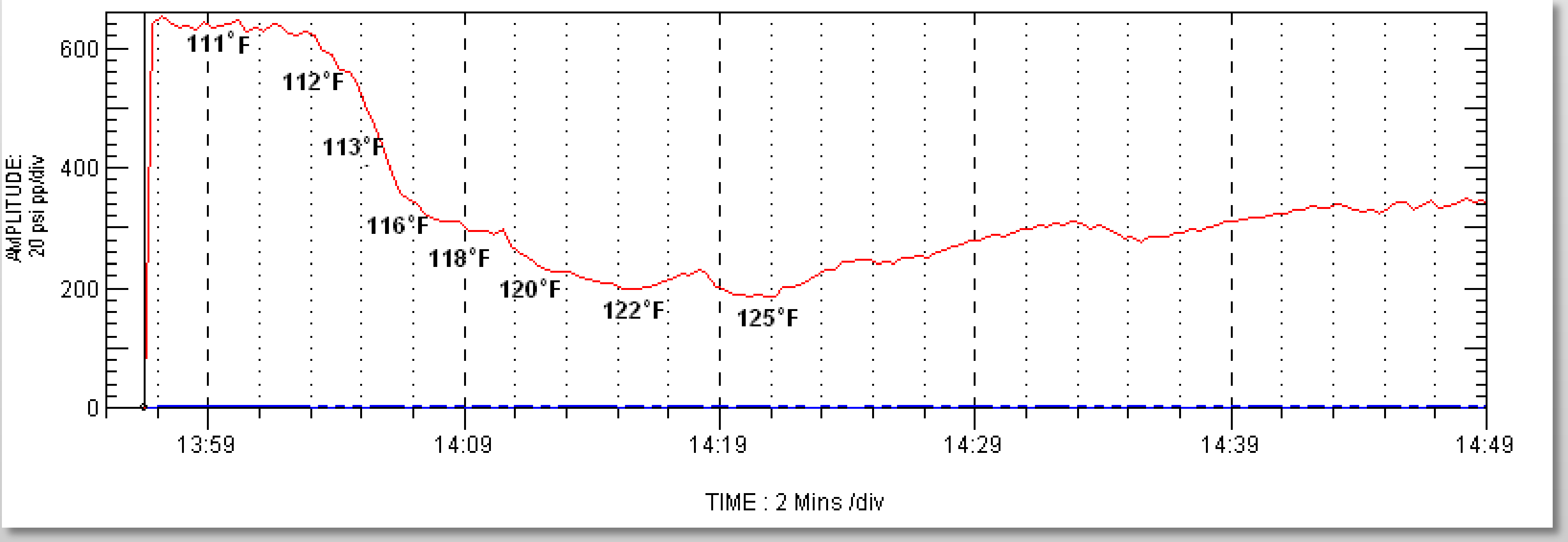
Pulsation Amplitudes at Recycle 126 deg F
P1:
P2: 237 psi p-p
P3: 223 psi p-p
P4:



Pulsation amplitudes at 300 Hz ranged from 230 – 280 psi as amount of recycle changed. This translated into approximately 2,000 lb shaking force.

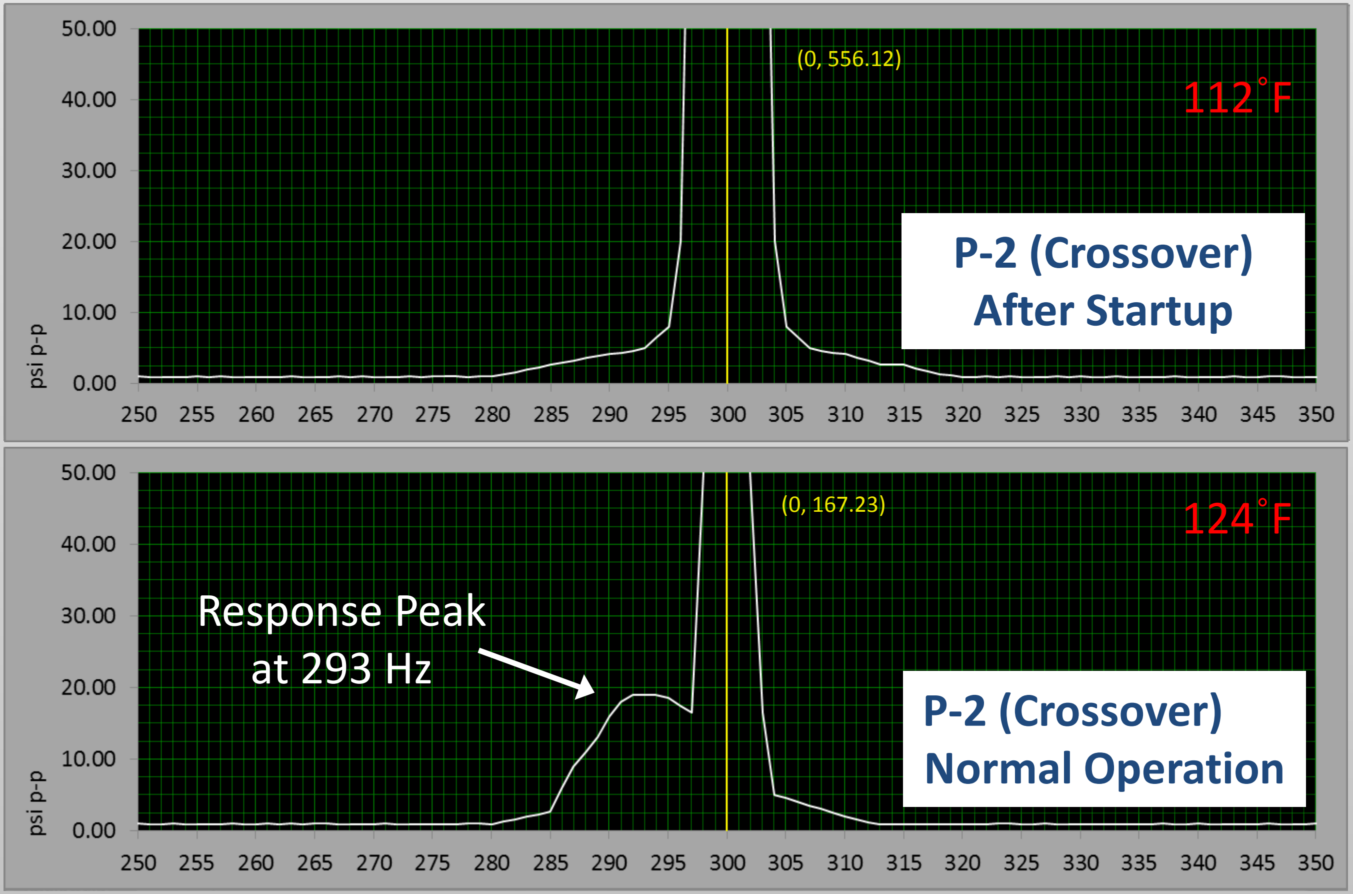
Pulsation Data

- Due to a shutdown of the pump, data was captured at a lower temperature
- The lower temperature case resulted in higher pulsation amplitude



Pulsation Data

- A closer view of the peak pulsation shows a shift in the acoustic response frequency



Impeller Vane Passing Pulsation

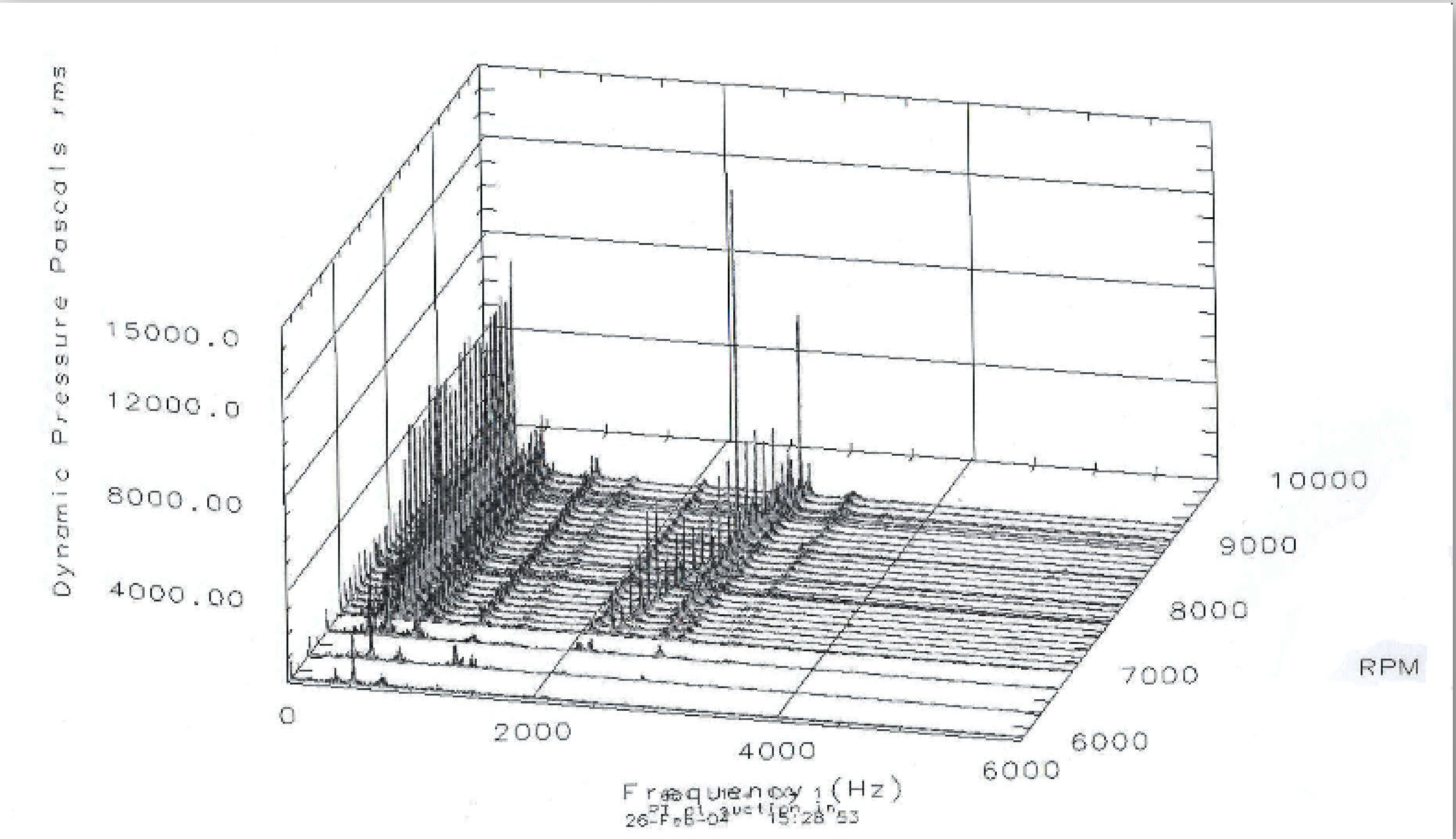
$$Freq_p = \frac{RPM \times n \times b}{60}$$

- RPM = running speed (60)
- b = number of vanes (5)
- n = Integer 1, 2, 3, …

n	$Freq_p$
1	300 Hz
2	600 Hz
3	900 Hz

- This pulsation frequency can excite the acoustic responses of pump internals as well as acoustic piping radial modes creating problematic resonances.
- This resulted in high vibration of over 1 ips at the bearing housing and 7 ips on the deck

Example Data Showing Blade Passing Frequency in Discharge Pulsation

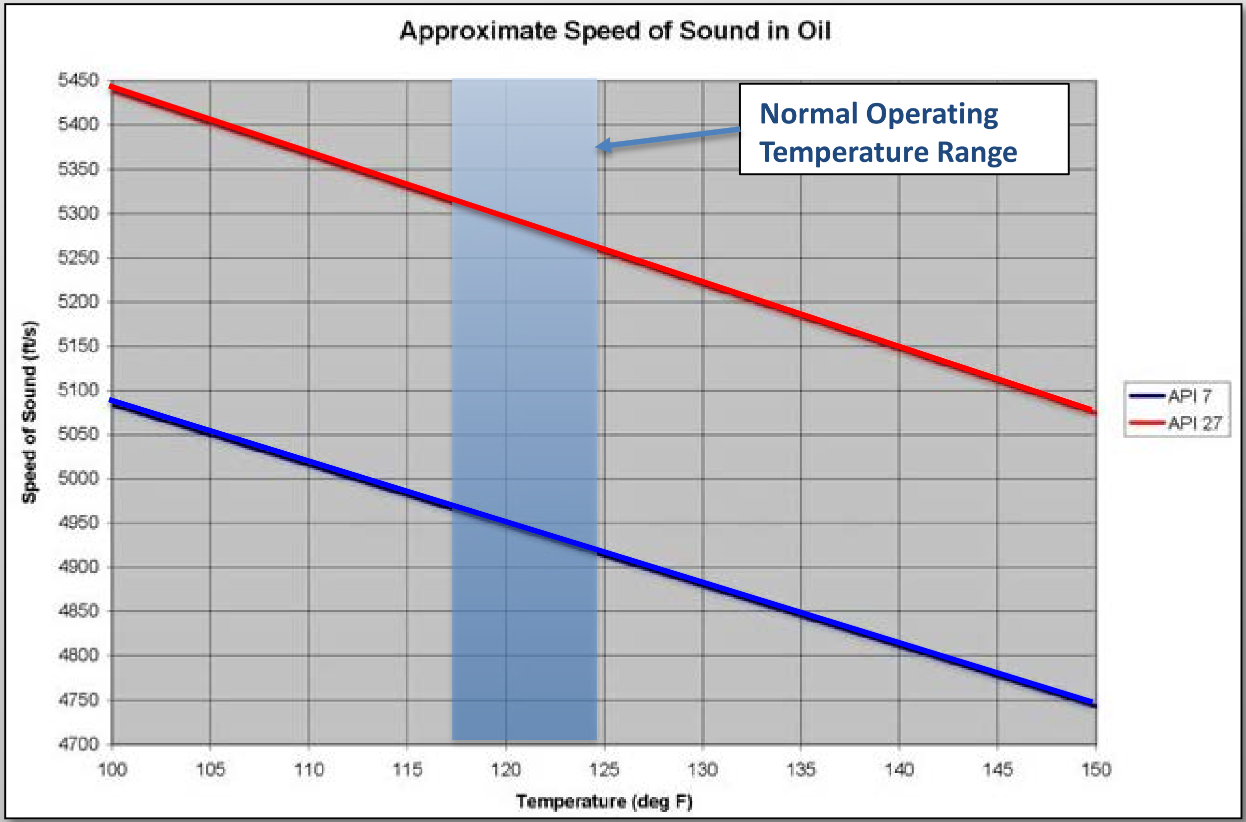


Speed of Sound in Oil

- API gravity is a measure of how heavy or light a petroleum liquid is compared to water: if its API gravity is greater than 10, it is lighter and floats on water; if less than 10, it is heavier and sinks.

$$SG\ at\ 60°F = \frac{141.5}{API\ gravity + 131.5}$$

- Medium crude oil can have an API gravity between 22° and 31°
- Extra heavy crude oil can have an API gravity less than 10°
- The chart below presents the change in speed of sound (S.O.S) for both densities with respect to temperature



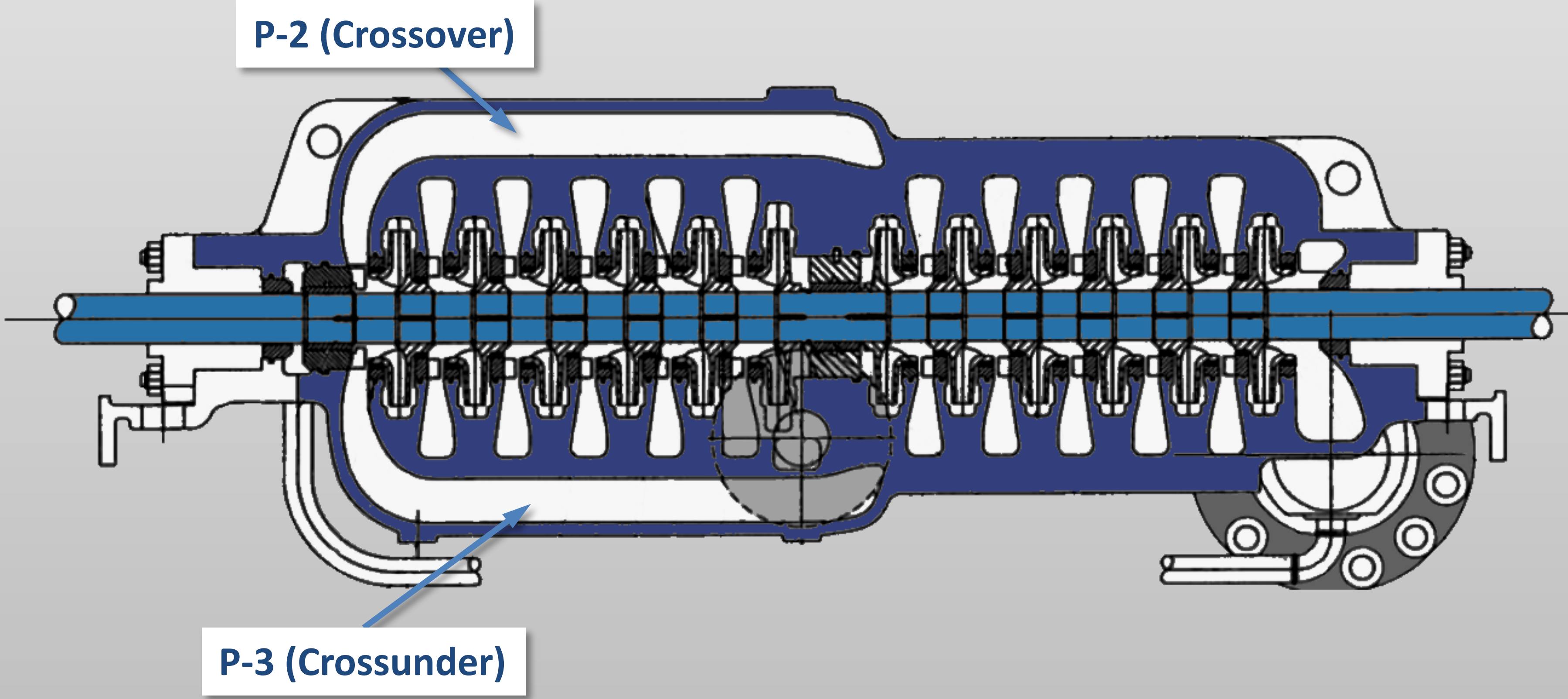
Acoustic Natural Frequencies

$$Freq = \frac{cn}{2L}$$

c = Speed of Sound (ranges from 5400 – 4875 ft/s)

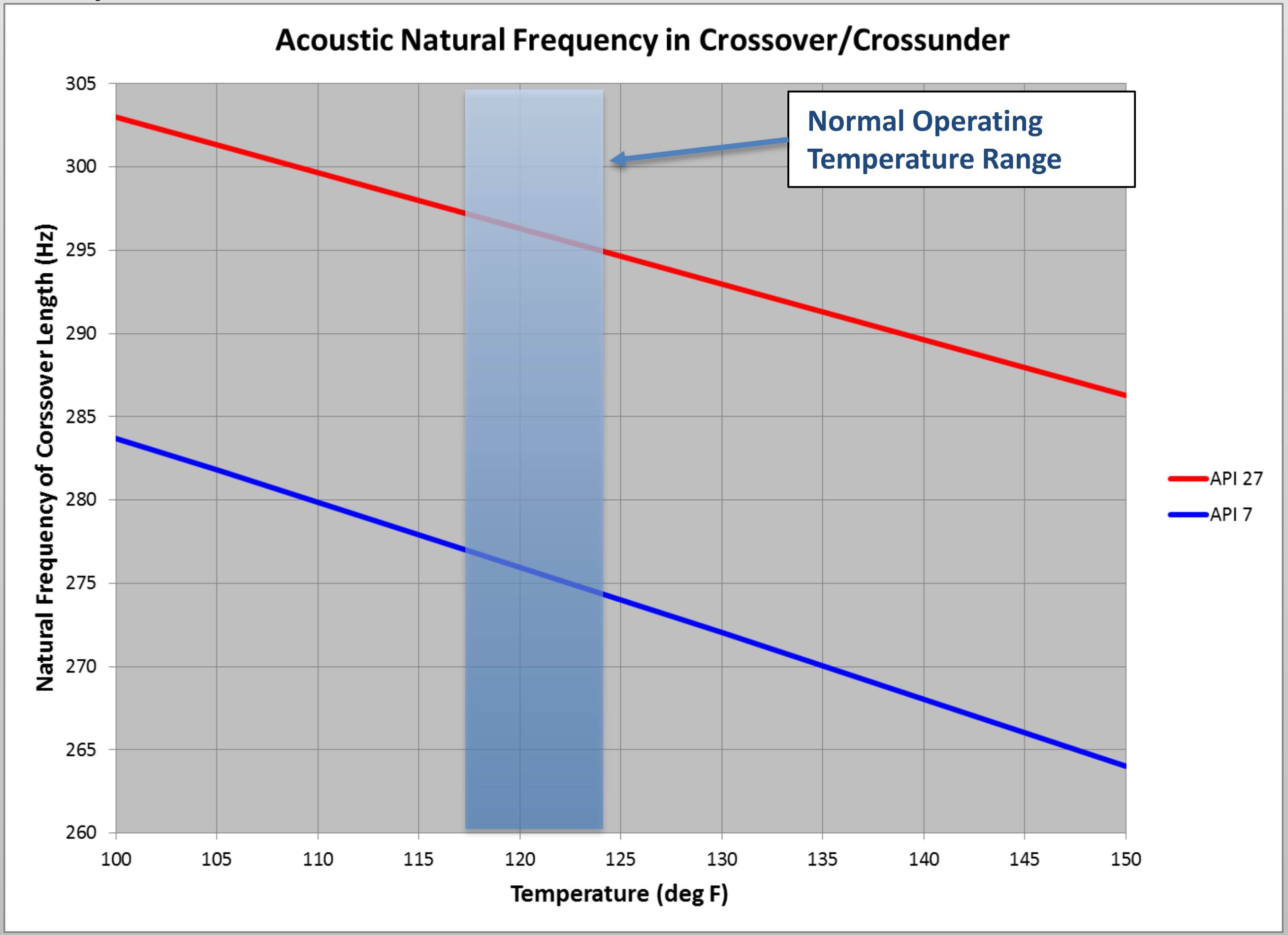
L = Length (approx. 9 ft)—length of crossover measured from the last 1st stage impeller (Impeller 6) to first 2nd stage impeller (Impeller 7)

n = mode number: 1,2,3,…



Acoustic Natural Frequency

- The chart below presents the change in natural frequency of the crossover with respect to temperature as well as showing how the frequency can changes with the composition of the oil from the wells.
- For normal operating conditions with the new well, the predicted natural frequency is between 297 Hz and 295 Hz.



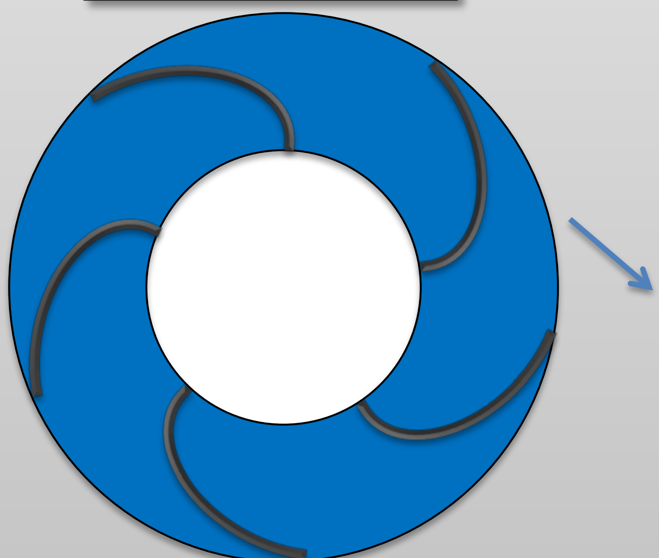
Short –Term Problem Resolution

- Temporary fix: raise crude oil temperature to approx. 120 deg F to reduce pulsations by increasing the % recycle
- Variation of fluid properties need considering for acoustic resonance
- Check and eliminate any mechanical resonances tuned for the new vane pass or other relevant frequencies
- Gusset/brace small bore piping connections back to main pipe

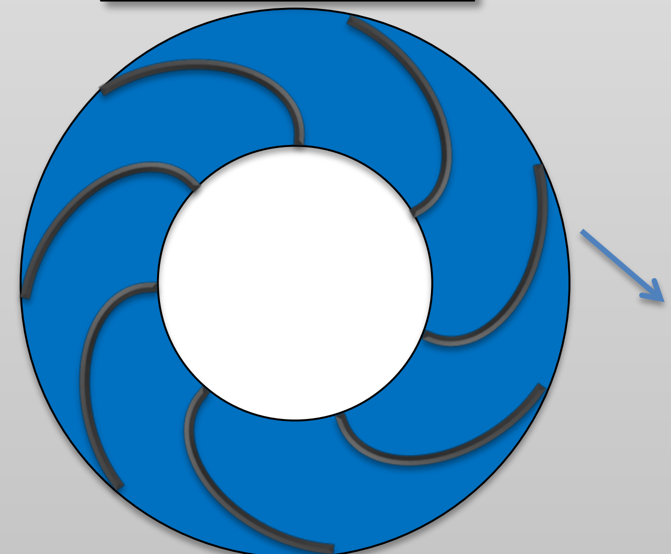
Long-Term Fix--Pump Modification

- Permanent fix: Replace existing 5 vaned impeller with a seven vaned impeller for impeller numbers 5 and 6.
  - Increase pulsation frequency to 420 Hz to avoid an acoustic resonance

5 Vaned Impeller
300 Hz at 60 rpm

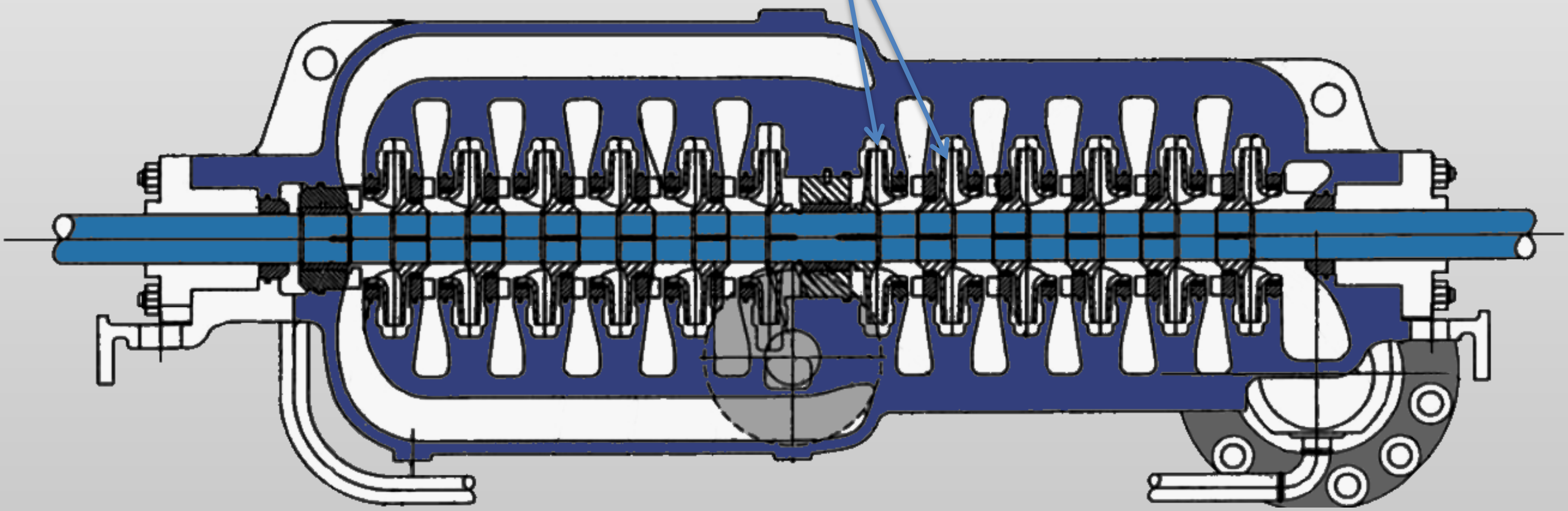


7 Vaned Impeller
420 Hz at 60 rpm



Impeller Modifications

Location of Modified Impellers



Changes to the impellers were implemented by the client and were reported to be successful at eliminating vibrations in the field

Questions or Comments?

Francisco Fierro
francisco.fierro@swri.org
210.522.2689

Sarah Simons
sarah.simons@swri.org
210.522.2418