44TH TURBOMACHINERY & 31ST PUMP SYMPOSIA
HOUSTON, TEXAS | SEPTEMBER 14 – 17 2015
GEORGE R. BROWN CONVENTION CENTER

Pipe Vibration Caused by Aero Excitation Resulted from a Foreign Object Lodged Inside an Impeller Passage

Dr. Zheji Liu
Mark J. Kuzdzal
Scott D. Wisler

September 17th 2015

DRESSER-RAND

TURBOMACHINERY LABORATORY
TEXAS A&M ENGINEERING EXPERIMENT STATION

TEXAS A&M UNIVERSITY

Biographies

Dr. Zheji Liu is Manager, Aerodynamics & Rotordynamics at Dresser-Rand. Since he joined Dresser-Rand in 1998, he has worked in the areas of aerodynamics, acoustics, and rotordynamics. Prior to joining Dresser-Rand, he worked briefly for Tenneco Automotive and the Trane Company. He Holds a Ph.D. in mechanical engineering from Purdue University.

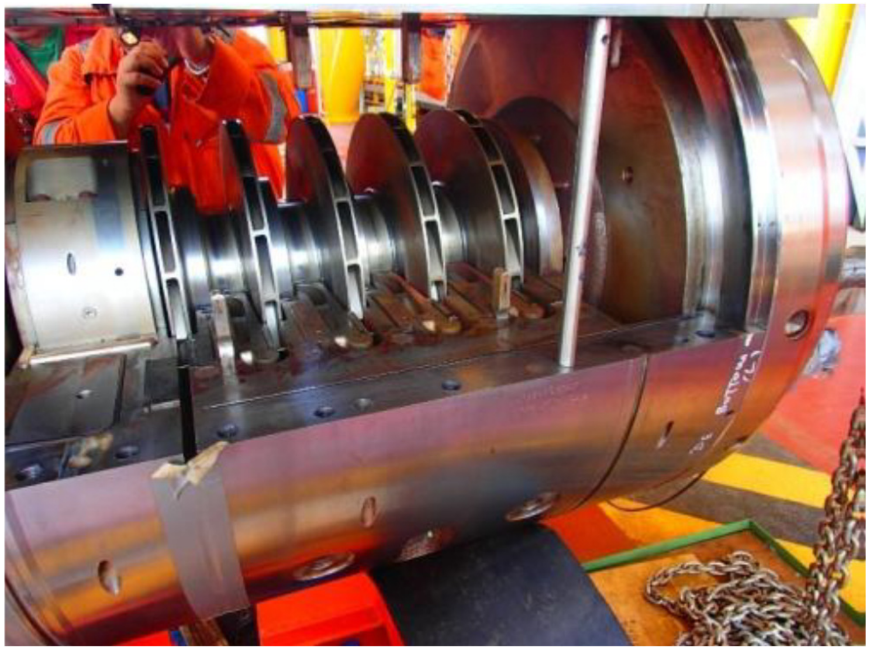
In 2011, Mark J. Kuzdzal was named as the Director of Business Development for D-R's supersonic compressor development initiative. Prior to this assignment and for nearly a decade, Mark was the Manager of the Core technologies organization for D-R Company. He was responsible for overseeing Rotordynamics, Materials & Welding, Solid Mechanics, Aero/thermo dynamics and Acoustics disciplines.

Mark started his career with D-R as a Rotordynamics engineer after earning a B.S. Degree (Mechanical Engineering, 1988) from the State University of New York at Buffalo. He has co-authored numerous technical papers and holds six U.S. Patents. Mr. Kuzdzal is a member of the Texas A&M turbo machinery advisory committee and the Penn State Mechanical Engineering Technology industrial advisory committee.

Introduction

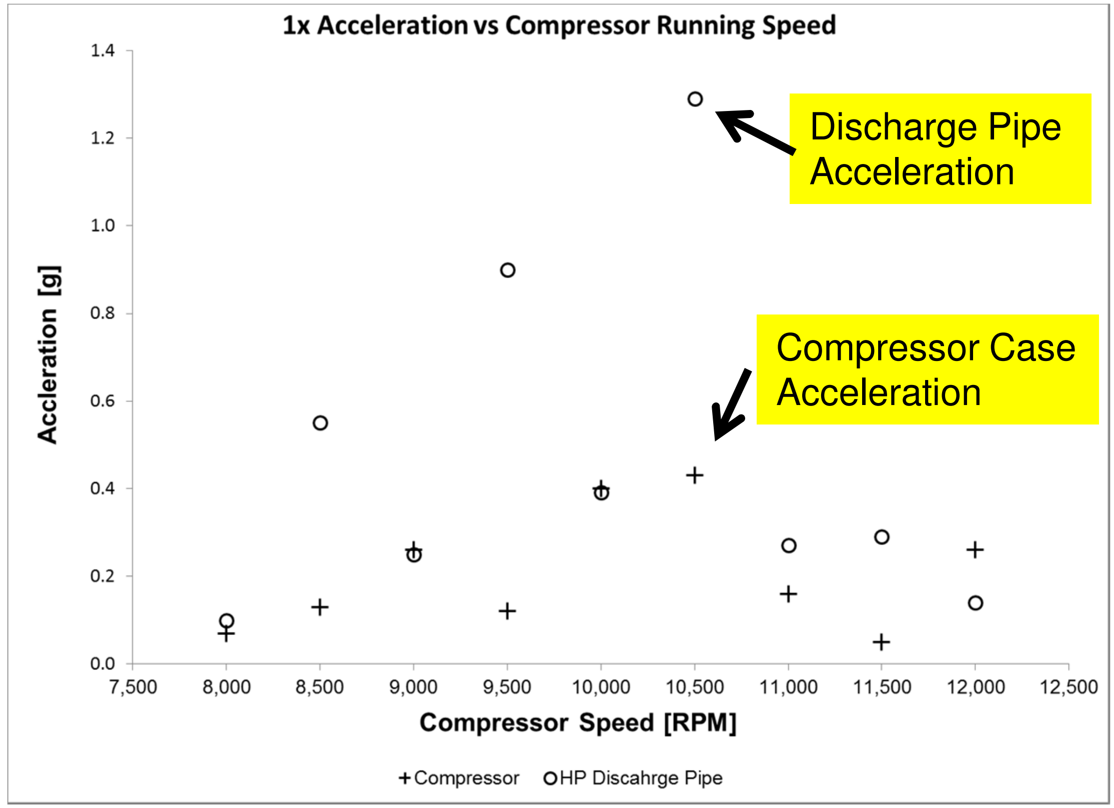
- Three identical centrifugal compressor trains installed on a gas injection platform were commissioned in 2014
- Each train has:
  - A gas turbine driver
  - A back-to-back centrifugal compressor
    - 9 stages
    - Power = 11,122 KW
    - Speed = 11,367 rpm
    - Mole weight = 19.24
    - P_{in}= 21.6 BarG
    - P_{out}=143 BarG

Compressor Configuration
9 Stage Back-to-Back



Vibration Problem on Unit # 1 During Commissioning

- One of the three compressor trains was observed with high discharge pipe vibration.
- High acceleration (g's) was reported on the discharge pipe of unit # 1
- Highest amplitude occurs at 1x rotor speed

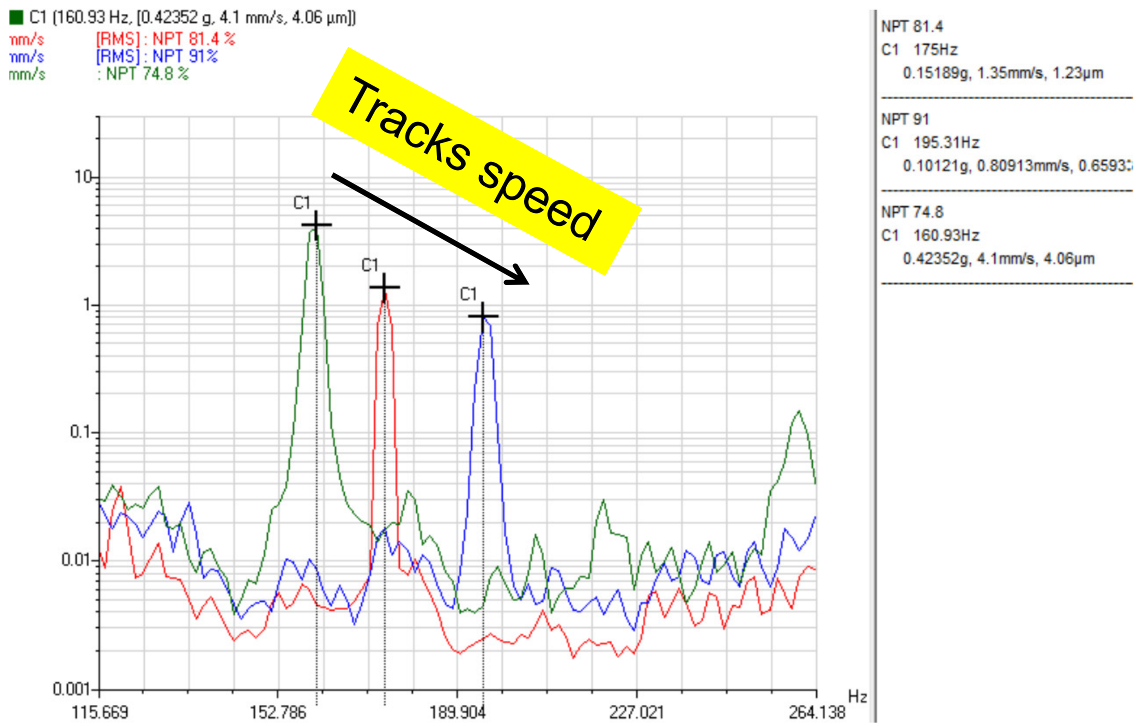


Possible Causes

- Structural / Acoustical Resonance
  - All three modules are piped the same
- Forced response due to
  - Mechanical excitation
    - Likely, compressor rotor produces synchronous vibration at 1x
  - Aerodynamics excitation
    - Commonly occurs at blade passing frequency (17x)
    - Uncommon for turbo compressors to produce strong 1x aero excitation

Diagnosis

- Pipe peak vibration frequency occurs at 1x and tracks with speed



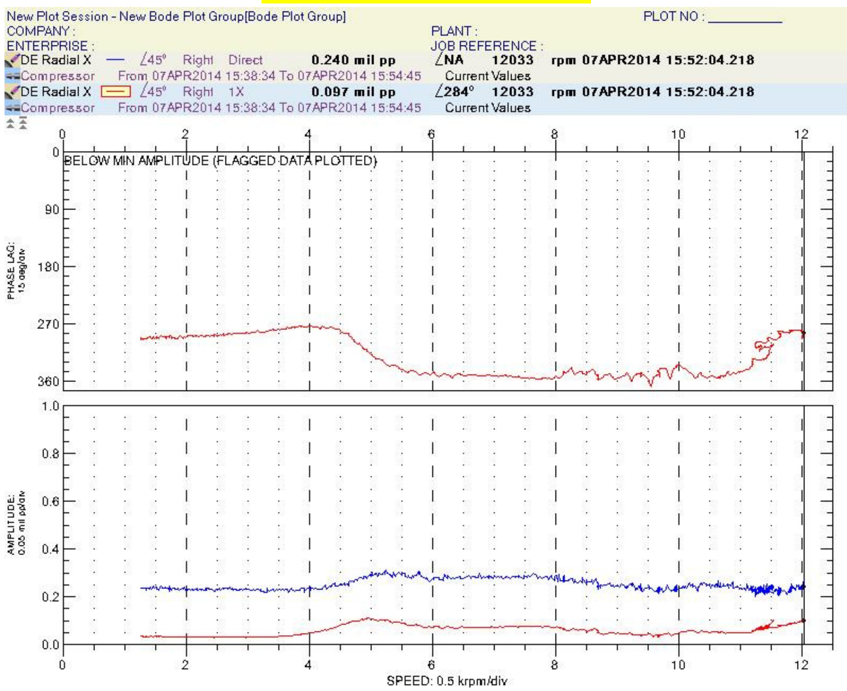
Mechanical and acoustical resonance is ruled out

Possible Causes

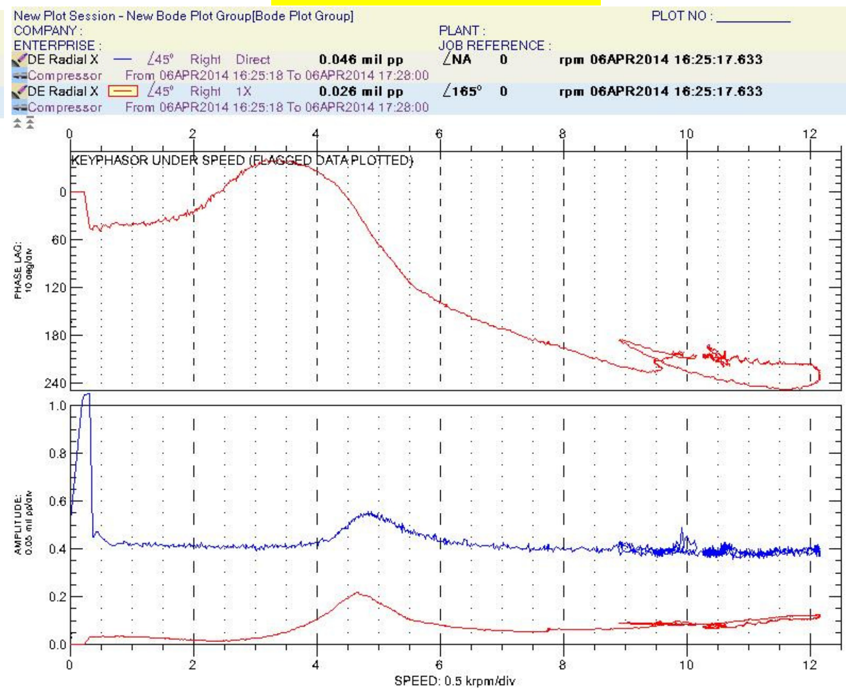
- ~~Structural / Acoustical resonance~~
  - ~~Not likely, as peak vibration amplitude tracks with speed~~
- Forced response due to
  - Mechanical excitation
    - Likely, compressor rotor produces synchronous vibration at 1x
  - Aerodynamics excitation
    - Commonly occurs at blade passing frequency (17x)
    - Uncommon for turbo compressors to produce strong 1x aero excitation

Comparing Compressor Rotor Vibration Drive End X

Shaft bode’



Shaft bode’



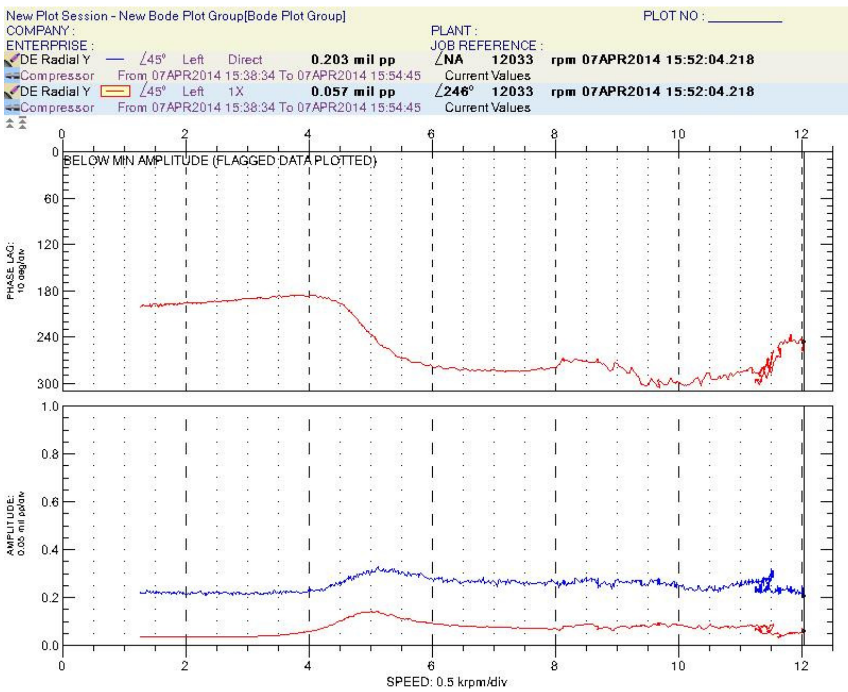
Unit # 1- High Pipe Vibration

Unit # 3 – Normal Pipe Vibration

Unit # 1 high pipe vibration has lower shaft vibration

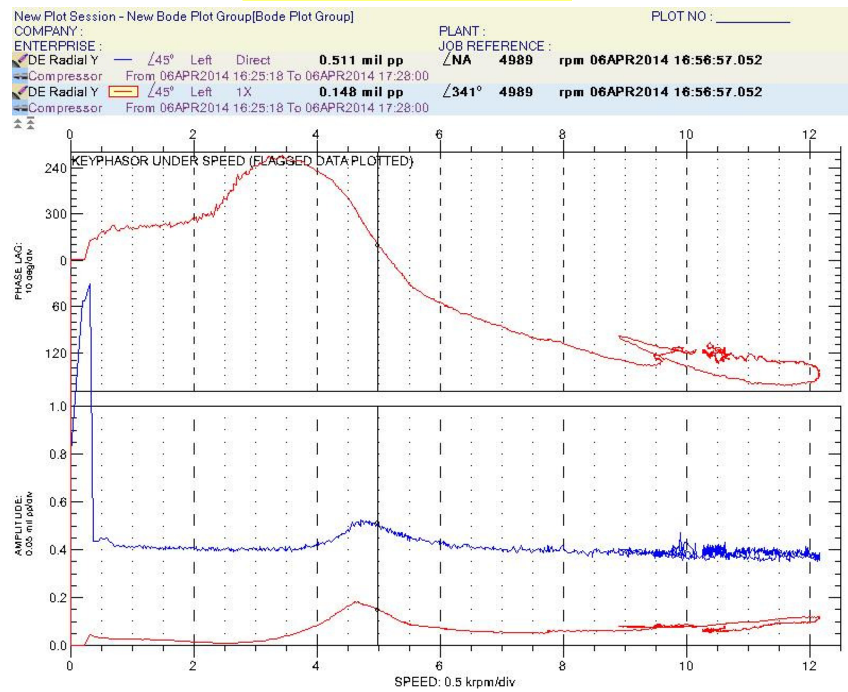
Comparing Compressor Rotor Vibration Drive End Y

Shaft bode



Unit # 1- High Pipe Vibration

Shaft bode

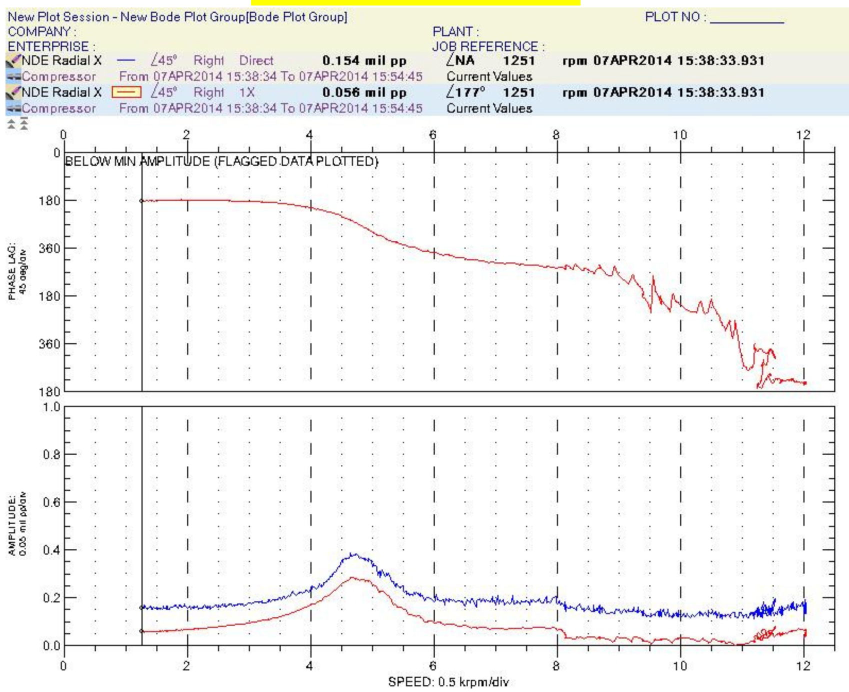


Unit # 3 – Normal Pipe Vibration

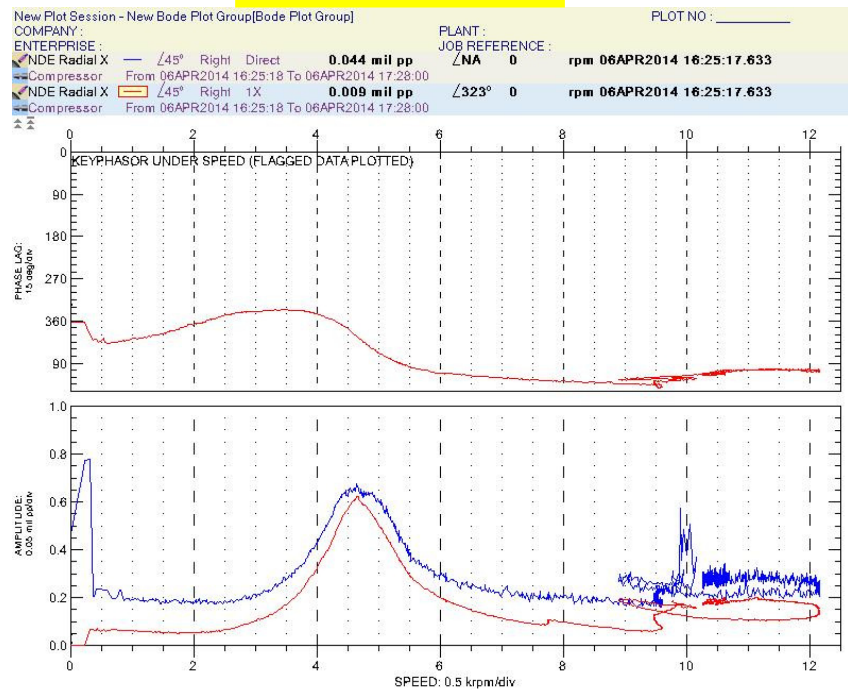
Unit # 1 high pipe vibration has lower shaft vibration

Comparing Compressor Rotor Vibration Non-Drive End X

Shaft bode



Shaft bode



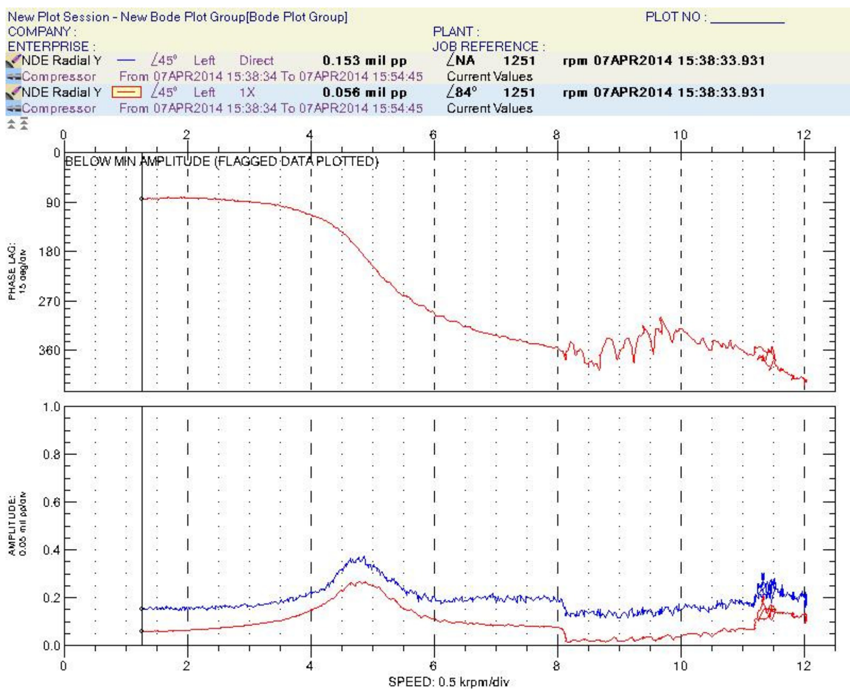
Unit # 1- High Pipe Vibration

Unit # 3 – Normal Pipe Vibration

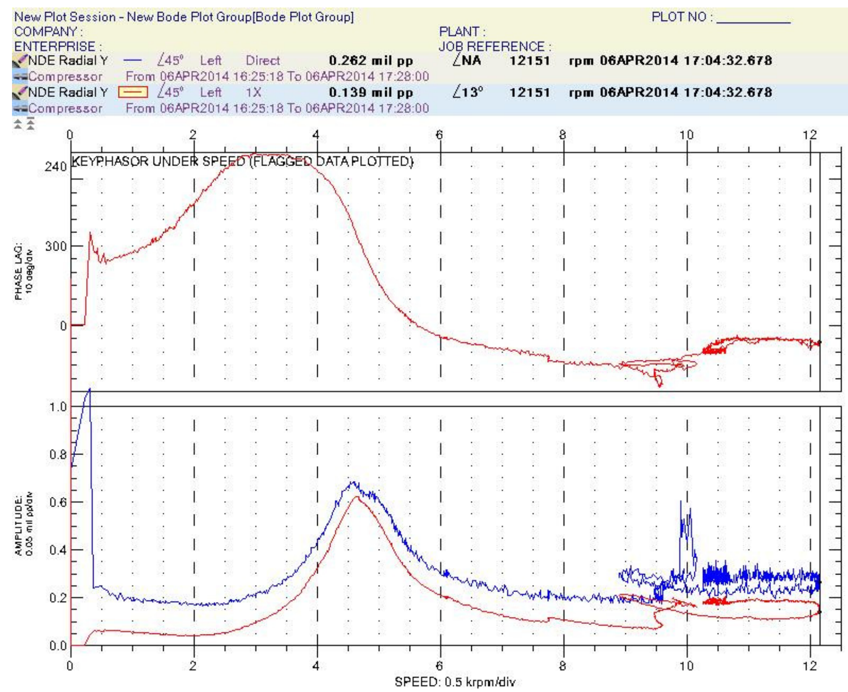
Unit # 1 high pipe vibration has lower shaft vibration

Comparing Compressor Rotor Vibration Non-Drive End Y

Shaft bode



Shaft bode



Unit # 1- High Pipe Vibration

Unit # 3 – Normal Pipe Vibration

Unit # 1 high pipe vibration has lower shaft vibration

Possible Causes

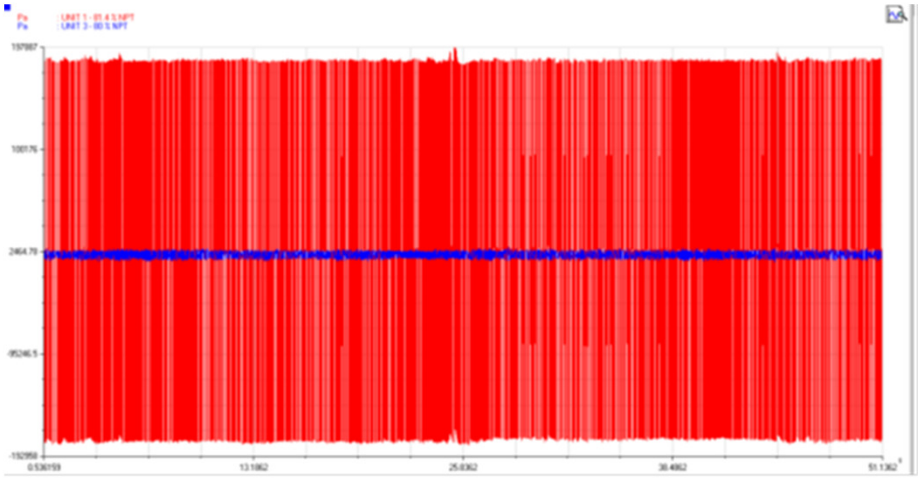
- ~~Structural / Acoustical resonance~~
  - ~~Not likely, as peak vibration amplitude tracks with speed~~
- Forced response due to
  - ~~Mechanical excitation~~
    - ~~Likely, compressor rotor produces synchronous vibration at 1x~~
    - All three compressors have low rotor vibration levels; the problem module actually has lower 1x rotor vibration than unit # 3
    - Hence, compressor rotor vibration is not likely the source of excitation
  - Aerodynamics excitation
    - Commonly occurs at blade passing frequency (17x)
    - Uncommon for turbo compressors to produce strong 1x aero excitation
    - Not likely, but is the only option not ruled out yet.

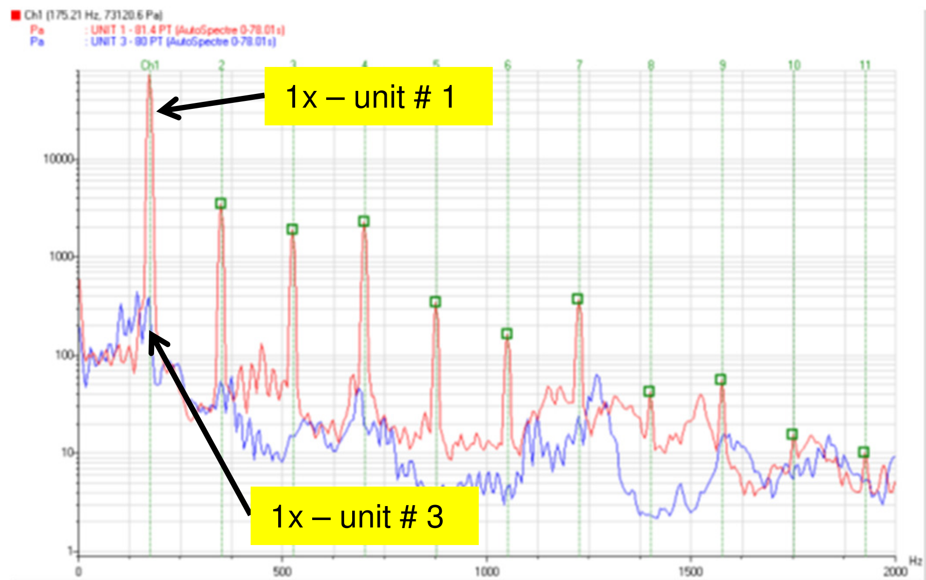
Pressure Pulsation Measurement

- As resonance and mechanical excitation were both ruled out as the cause of the pipe vibration of Unit # 1, aero excitation had to be considered next.
- A dynamic pressure probe was inserted to measure the discharge pipe internal pressure pulsations of Units #1 and #3
- Purpose was to identify if there was an internal pressure pulsation difference between a Unit #1 and Unit #3

Units #1 and #3 Pressure Pulsations

- Time domain pressure fluctuation of Unit #1 is 100 times higher than that of Unit #3
- Frequency domain spectrum comparison shows the same higher amplitudes in Unit # 1





How Could a Turbo Compressor Produce 1x Pipe Pressure Excitation?

- If the impeller tip speed was supersonic it may cause a "Buzz Saw" tone that may have a strong 1x
  - $U2/A_0$ ~0.6, not supersonic
- One impeller blade is longer or shorter than others
  - Impellers were 5 axis milled, variation is minimal and parts conform to drawing tolerances
- Is one impeller passage working harder than others? Or vice versa?

Starved Impeller Passage

Disassembly of the compressor revealed about 50% of one impeller passage was blocked

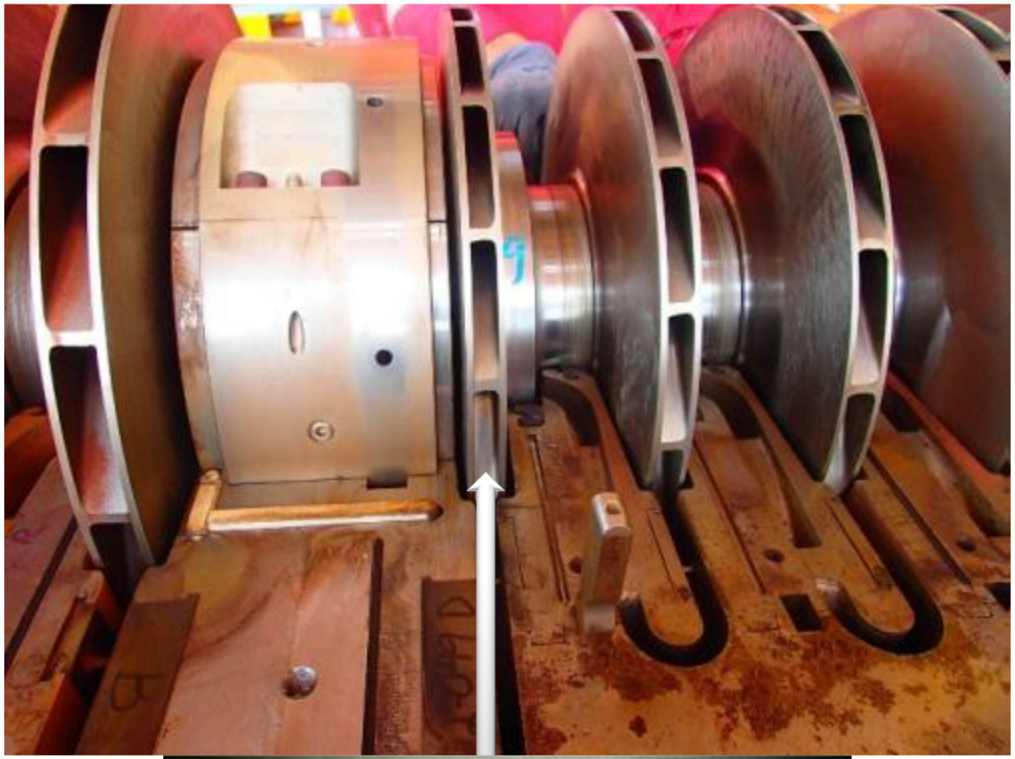
Foreign Object (Teflon) Found

- Teflon like material was lodged in a blade passage of the last stage impeller.

Approximately 12 mm or 0.5 inches

Inspection Photos

- The last stage impeller typically has the narrowest passage width and was small enough to catch the Teflon.



Conclusions

- The foreign object lodged in a blade passage of the last stage impeller restricted flow and made that passage work significantly less than the other 16 passages.
- This uneven mass flow distribution at the impeller exit generated a 1x aero-acoustic excitation.
- The high vibration and noise on the discharge pipe was in response to this 1x aero excitation.
- Removal of the foreign object from the impeller passage resolved this field pipe vibration problem.
- Since the foreign object found lodged in the last stage impeller passage was Teflon and light in density, it did not contribute enough unbalance weight to make the rotor vibration noticeably different.

Questions