ASIA TURBOMACHINERY & PUMP SYMPOSIUM
APRIL 2020 | KUALA LUMPUR CONVENTION CENTRE

Identification and Mitigation of H2 Recycle Gas Compressor Blade Pass Resonance

TEXAS A&M UNIVERSITY

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He received a Bachelor of Engineering degree(Mechanical,2009) from the National Institute of Technology, Surathkal, India.

Abstract

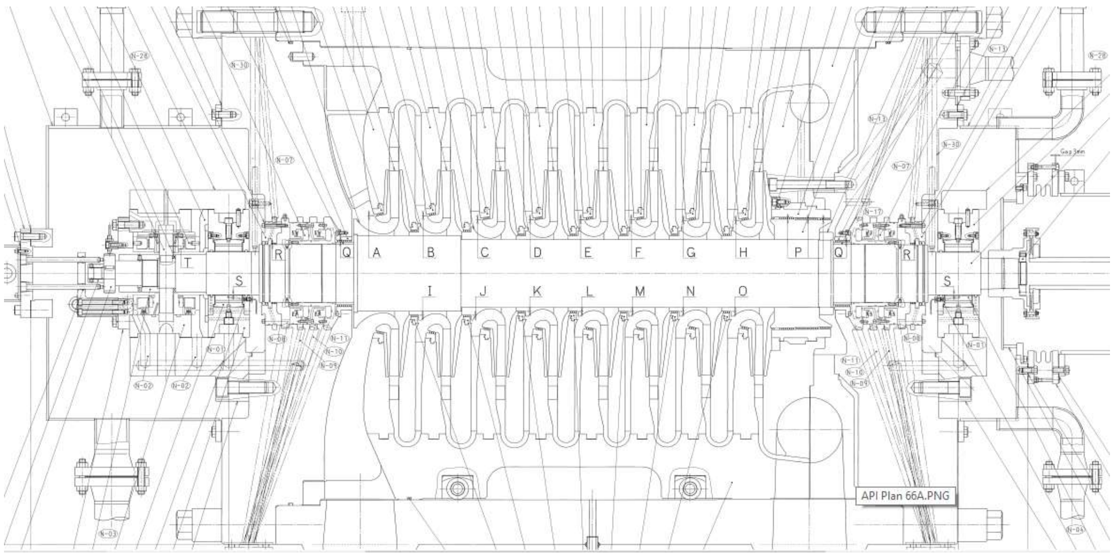
- H2 recycle gas compressor C10101 in the SHDS unit was experiencing intermittent vibration spikes. Review of the vibration waterfall plot revealed spikes appearing at 11x the running speed of the compressor. The no. of blades of the impeller is 11. Vibrations and would increase from normal of 0.5 mil pp to 1 mil pp and sometimes to 1.5 mils pp. Alarm: 2 mils pp, trip: 3 mils pp.
- Initially presumed to be liquid carryover to the compressor, but no evidence for the same was found.
- Further investigation revealed vibration spikes are occurring only in a specific speed band, i.e. 8800rpm to 9150 rpm. This correlation was consistent throughout and prevalent since commissioning in 2013.
- Detailed analysis confirmed blade pass resonance coinciding with the 19^{th} eigenvalue of the rotor at that particular speed range. The blade pass resonance was ascertained to be due to acoustic resonance.
- Larger concern of impeller damage due to acoustic resonance studied. Campbell and SAFE diagram revealed no interference with the impeller nodal diameter modes.
- Permanent mitigation would require removal of diffuser vanes (of all stages, since location of resonance is not identifiable), this would consequently cause the compressor efficiency to drop significantly and hence is not being pursued.
- Vibration spikes within alarm limits, hence, recommended to continue operating the machine but avoid the speed range of 8800-9150 rpm.

Agenda

1. Machine Detail
2. Problem Statement / Observations
3. Analysis
4. Trend
5. Analysis
6. Solution
7. Broader learnings

Machine Details

- H2 recycle gas 8 stage centrifugal compressor
- Motor (VFD) + step up gearbox drive.
- Operating speed range: 5170-10800 rpm
- Resonance range: 8800-9150 rpm
- No. of blades in impeller: 11
- No. of vanes in diffuser: 12
- Speed range in which vibration occurs: 8800-9150 rpm



Problem Statement /Observations

- Compressor experiencing intermittent vibration spikes at 11x of running speed
- Vibration spiking only in a specific speed range- 8800 rpm to 9150 rpm
- Vibration spiking from a normal operating value of 0.5 mils up to 1.5 mils.
- Vibration alarm and trip values at 2 mils and 3 mils respectively.
- Vibration spiking on compressor drive and non-drive end both.
- When compressor not in the specific operating speed range of 8800-9150 rpm, vibrations are low and steady at around 0.5 mils.

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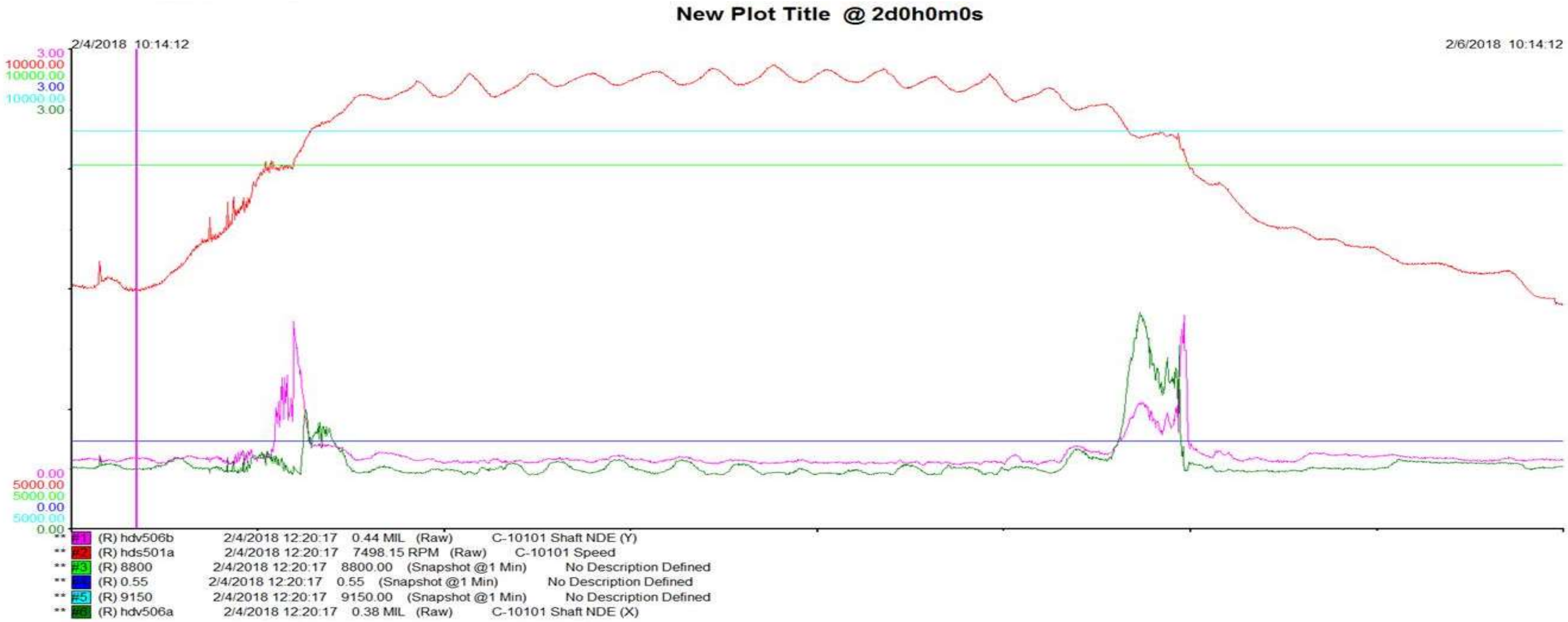
Analysis

- **Process parameters:**
  - Initially, vibration spikes suspected due to process related parameters. Liquid carry over causing blade pass frequency was suspected.
  - Parameters related to process conditions such as suction drum level, process temperature, hydrogen purity, anti-surge valve opening were studied.
  - No specific correlation found with 11x vibration spikes.

Analysis

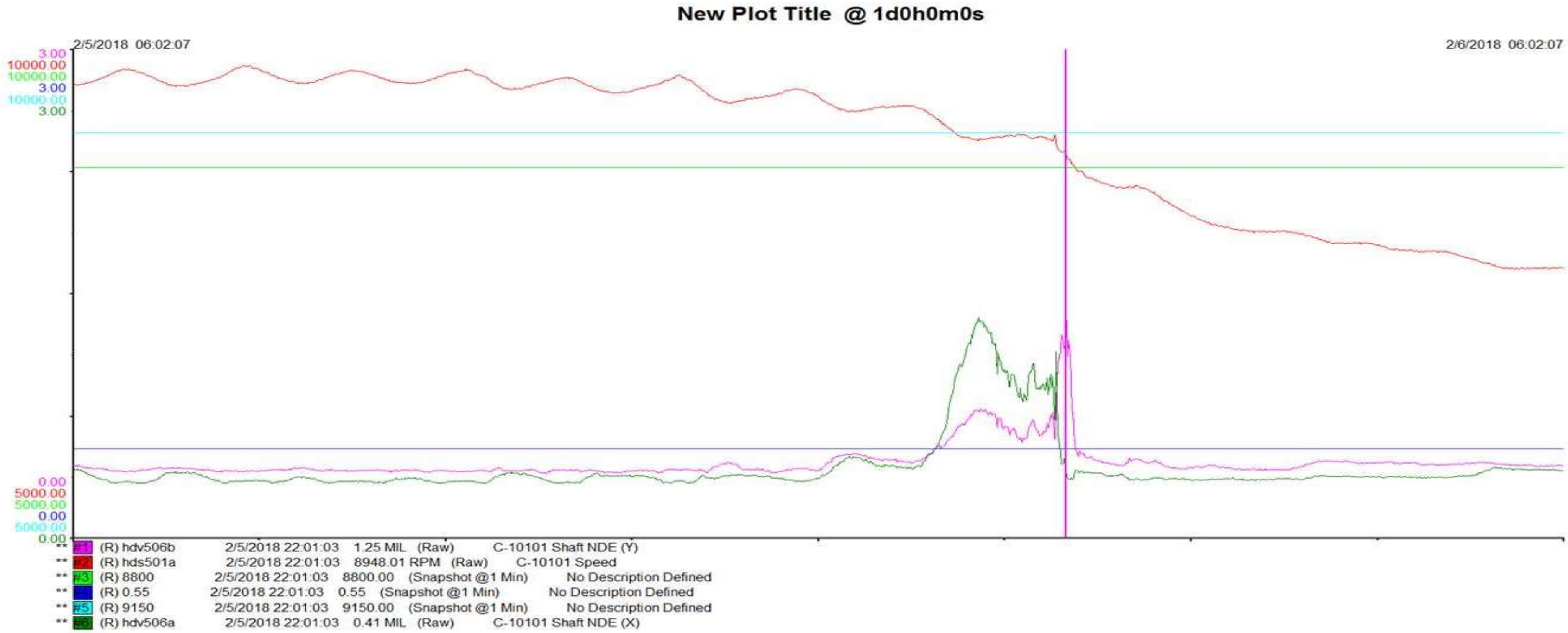
- **Speed correlation:**
  - Vibration spikes were independently studied with speed of the compressor.
  - Direct & precise correlation of vibration spikes with speed found in range of 8800 rpm to 9150 rpm.
  - It was ascertained that resonance was occurring in the specified speed range.
  - Resonance occurring at 11X 9000 rpm = 99000cpm = 1650 Hz.

Trends

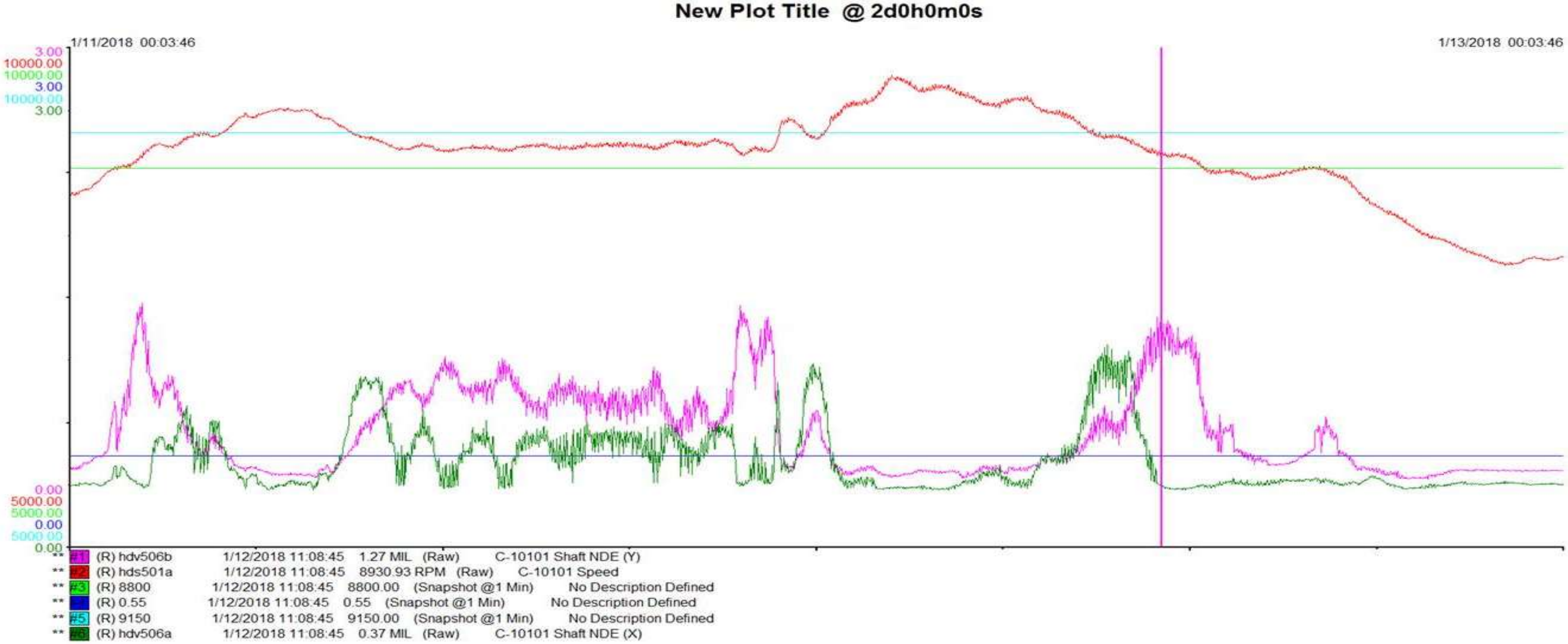


New Plot Title @ 2d0h0m0s
2/4/2018 10:14:12
2/6/2018 10:14:12
3.00
10000.00
10000.00
3.00
10000.00
3.00
0.00
5000.00
5000.00
0.00
5000.00
0.00
** #1 (R) hdv506b 2/4/2018 12:20:17 0.44 MIL (Raw) C-10101 Shaft NDE (Y)
** #2 (R) hds501a 2/4/2018 12:20:17 7498.15 RPM (Raw) C-10101 Speed
** #3 (R) 8800 2/4/2018 12:20:17 8800.00 (Snapshot @1 Min) No Description Defined
** #4 (R) 0.55 2/4/2018 12:20:17 0.55 (Snapshot @1 Min) No Description Defined
** #5 (R) 9150 2/4/2018 12:20:17 9150.00 (Snapshot @1 Min) No Description Defined
** #6 (R) hdv506a 2/4/2018 12:20:17 0.38 MIL (Raw) C-10101 Shaft NDE (X)

Trends


New Plot Title @ 1d0h0m0s
2/5/2018 06:02:07
2/6/2018 06:02:07
3.00
10000.00
10000.00
3.00
10000.00
3.00
0.00
5000.00
5000.00
0.00
5000.00
0.00
#1 (R) hdv506b 2/5/2018 22:01:03 1.25 MIL (Raw) C-10101 Shaft NDE (Y)
#2 (R) hds501a 2/5/2018 22:01:03 8948.01 RPM (Raw) C-10101 Speed
#3 (R) 8800 2/5/2018 22:01:03 8800.00 (Snapshot @1 Min) No Description Defined
#4 (R) 0.55 2/5/2018 22:01:03 0.55 (Snapshot @1 Min) No Description Defined
#5 (R) 9150 2/5/2018 22:01:03 9150.00 (Snapshot @1 Min) No Description Defined
#6 (R) hdv506a 2/5/2018 22:01:03 0.41 MIL (Raw) C-10101 Shaft NDE (X)

Trends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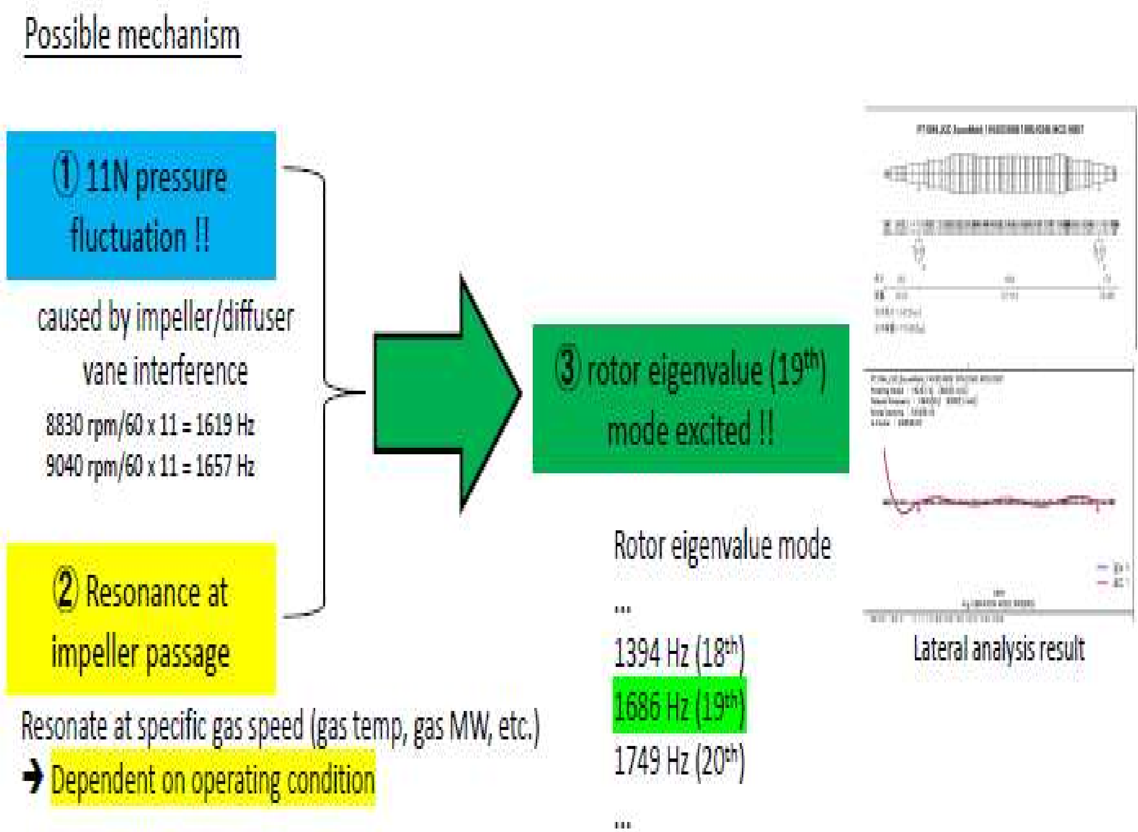
1/13/2018 00:03:46
3.00
10000.00
10000.00
3.00
10000.00
3.00
0.00
5000.00
5000.00
0.00
5000.00
0.00
** #1 (R) hdv506b 1/12/2018 11:08:45 1.27 MIL (Raw) C-10101 Shaft NDE (Y)
** #2 (R) hds501a 1/12/2018 11:08:45 8930.93 RPM (Raw) C-10101 Speed
** #3 (R) 8800 1/12/2018 11:08:45 8800.00 (Snapshot @1 Min) No Description Defined
** #4 (R) 0.55 1/12/2018 11:08:45 0.55 (Snapshot @1 Min) No Description Defined
** #5 (R) 9150 1/12/2018 11:08:45 9150.00 (Snapshot @1 Min) No Description Defined
** #6 (R) hdv506a 1/12/2018 11:08:45 0.37 MIL (Raw) C-10101 Shaft NDE (X)

Analysis

- **Resonance analysis:**
  - Rotor critical speed clearly not in the operating range of the machine.
  - Rotor 1st critical at 3550 rpm and 2nd critical at 14400 rpm.
  - Direct rotor critical speed excitation ruled out.
  - Further analysis done by checking impeller Campbell diagram and SAFE diagram.

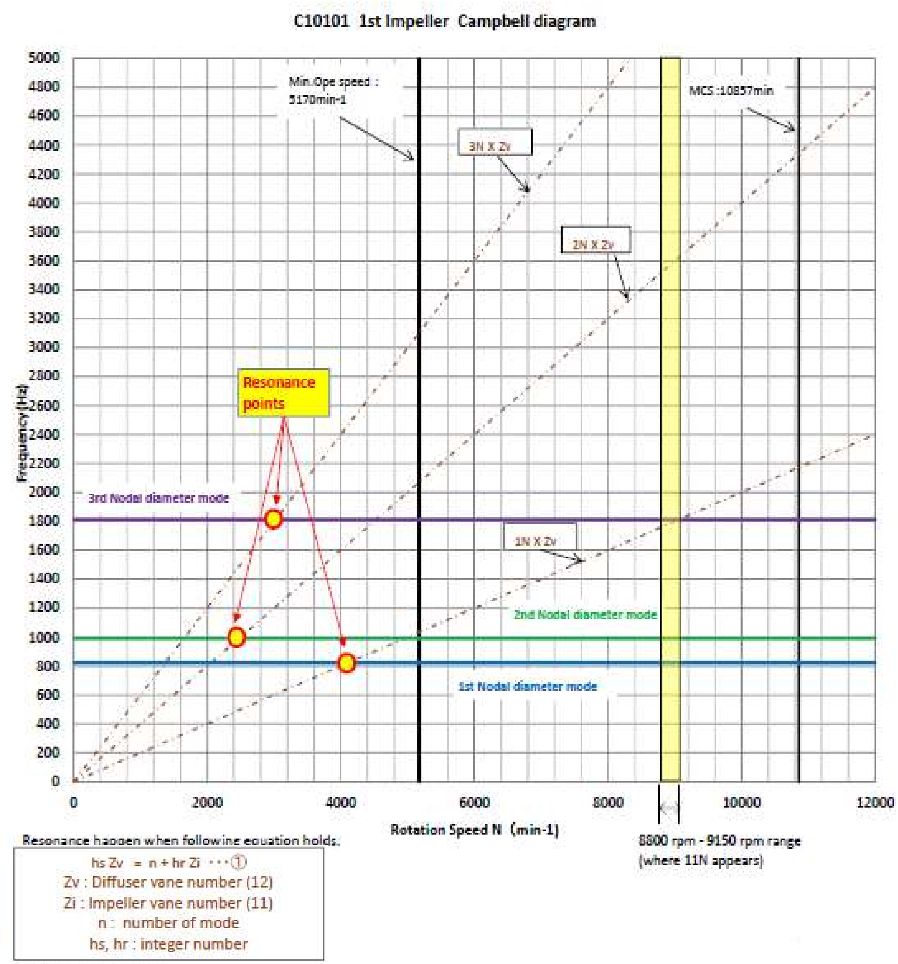
Analysis

- **11x pressure fluctuation:**
  - 11x pressure fluctuation exciting the 19th eigenvalue of the rotor.
  - 19th eigenvalue of rotor coinciding with 11X of the rotor.



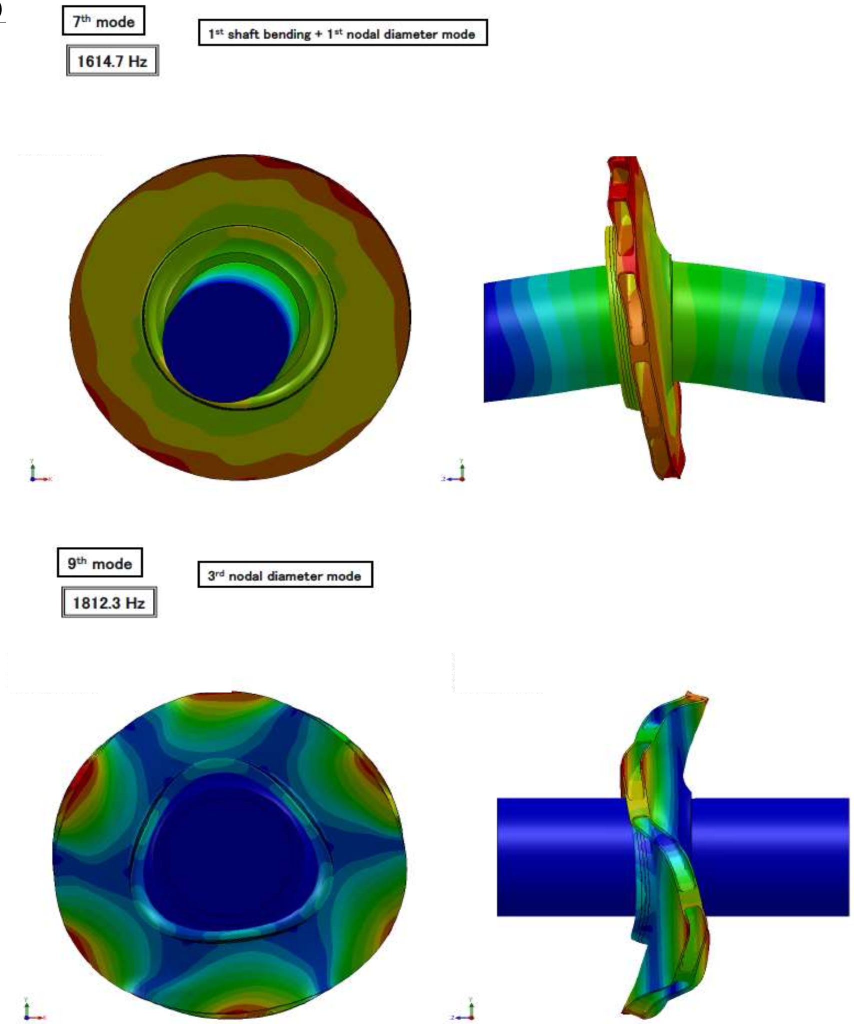
Analysis

- **Campbell diagram:**
  - No resonance nodes in the operating range of the machine.
  - Impeller nodal diameter modes also checked for interference.
  - No interference found.



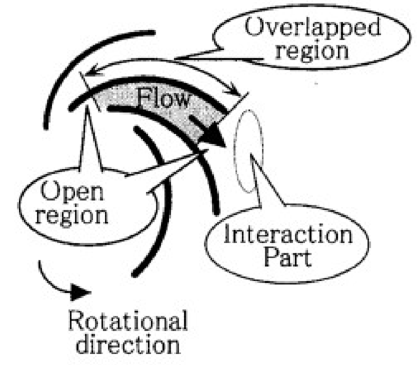
Analysis

- **Impeller nodal diameter mode:**
  - Impeller nodal diameter modes checked.
  - Impeller nodal diameter modes not coinciding with resonant frequency.
  - Risk of impeller damage due to impeller resonance ruled out.



Analysis

- **Acoustic resonance:**
  - Acoustic resonance occurring between impeller blade passages.
  - Based on gas velocity and blade length and sound velocity, acoustic resonance natural frequency ascertained to be 1742 Hz, in operating speed range of 8800 to 9150 rpm.



$$f_r = \frac{a}{\lambda} = \frac{a}{4l} = \frac{1066}{4 \times 0.153} = 1742 \text{ Hz}$$

where

f_r : Acoustic resonance frequency on Rotational coordinate system, Hz

λ : Wave length, m

a : Sound velocity, m/s

l : Effective tube length, m

Analysis

- **Acoustic resonance:**
  - Sound velocity for the gas, and the effective length in gap between the blades produces the open ended acoustic wave.
  - The frequency of the acoustic wave coincides with the 19th eigenvalue of the rotor causing vibration.

(Cross sectional view of impeller)
Fig. 1 Result of acoustic modal analysis for the impeller of compressor experienced "11N" vibration

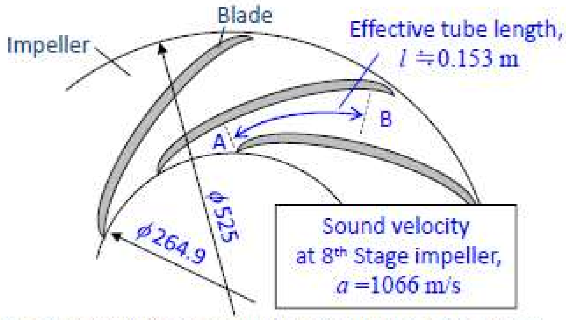


Fig. 2 Acoustic tube model for 8th Impeller of C-10101

Analysis

- Why 11x is answered in the graphic below:

$$f_s = 11 f_N = 11 \times \frac{f_r}{12} = 11 \times \frac{1742}{12} = 1597 \text{ Hz}$$

where

f_s : Rotor excitation frequency on Static coordinate system, Hz

f_N : Rotating frequency, Hz

f_r : Acoustic resonance frequency on Rotational coordinate system, Hz

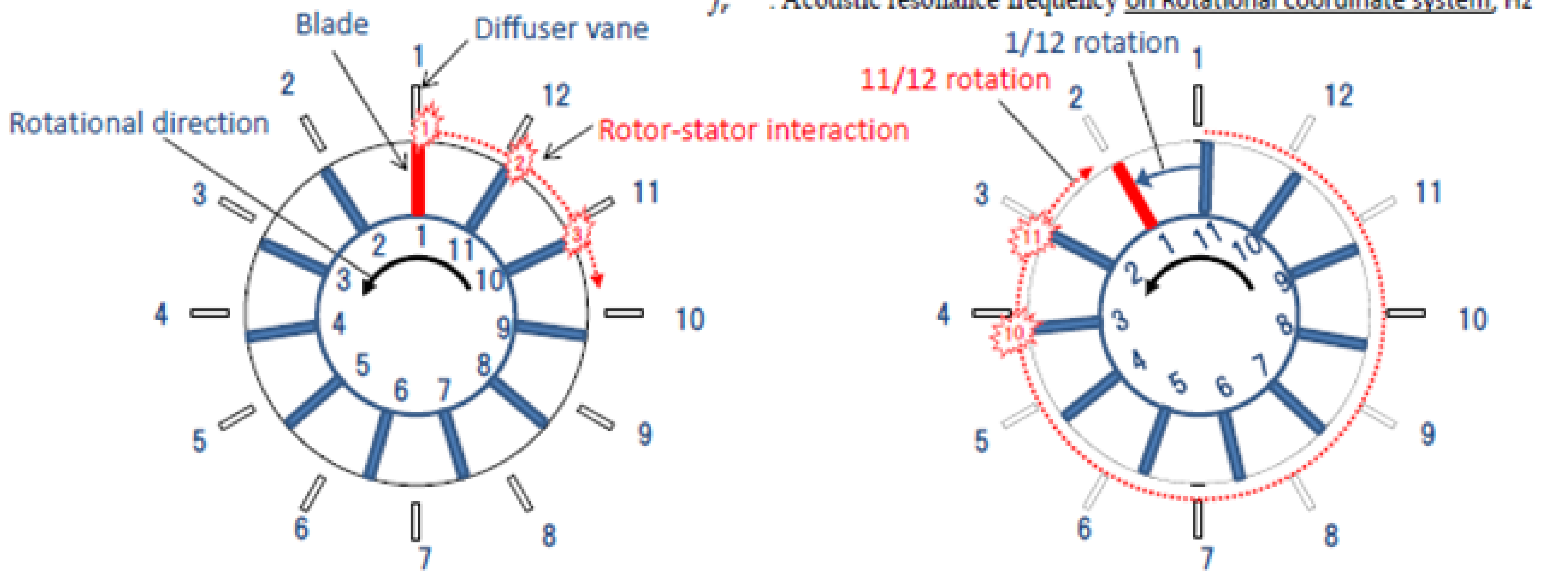


Fig. 3 Rotor-stator interaction for Impeller of C-10101

Solution

- **Mitigation of 11x acoustic resonance**
  - Mitigation of 11x acoustic resonance would require removal of the diffuser vanes OR
  - Increase in clearance between the impeller blade tip and diffuser vanes.
  - Both would require major modification in machine, especially diffusers.
  - Primarily because, it is not possible to determine, the stage in which resonance is occurring. All stages would need to be modified.

Solution

- **Low cost / minimalistic solution**
  - It is recommended to **avoid operating** in the speed range (8800 rpm to 9150 rpm) that causes the resonance issue till compressor overhaul is performed.
  - Avoiding the specified speed range helps avoid vibration spikes and any concerns of damage of impeller.
  - Operations advised on the same. Logic to avoid specific speed range being explored.

Broader learnings

- Complete speed range test of the compressor to be performed at site conditions (if required at site, if site conditions are only available at site) to ascertain the rotodynamic performance of the rotor at operating conditions.
- To check for interference of acoustic resonance of the rotor within the operating speed range of the machine (uncommon phenomenon but can be checked).

Thank you

Any questions please?