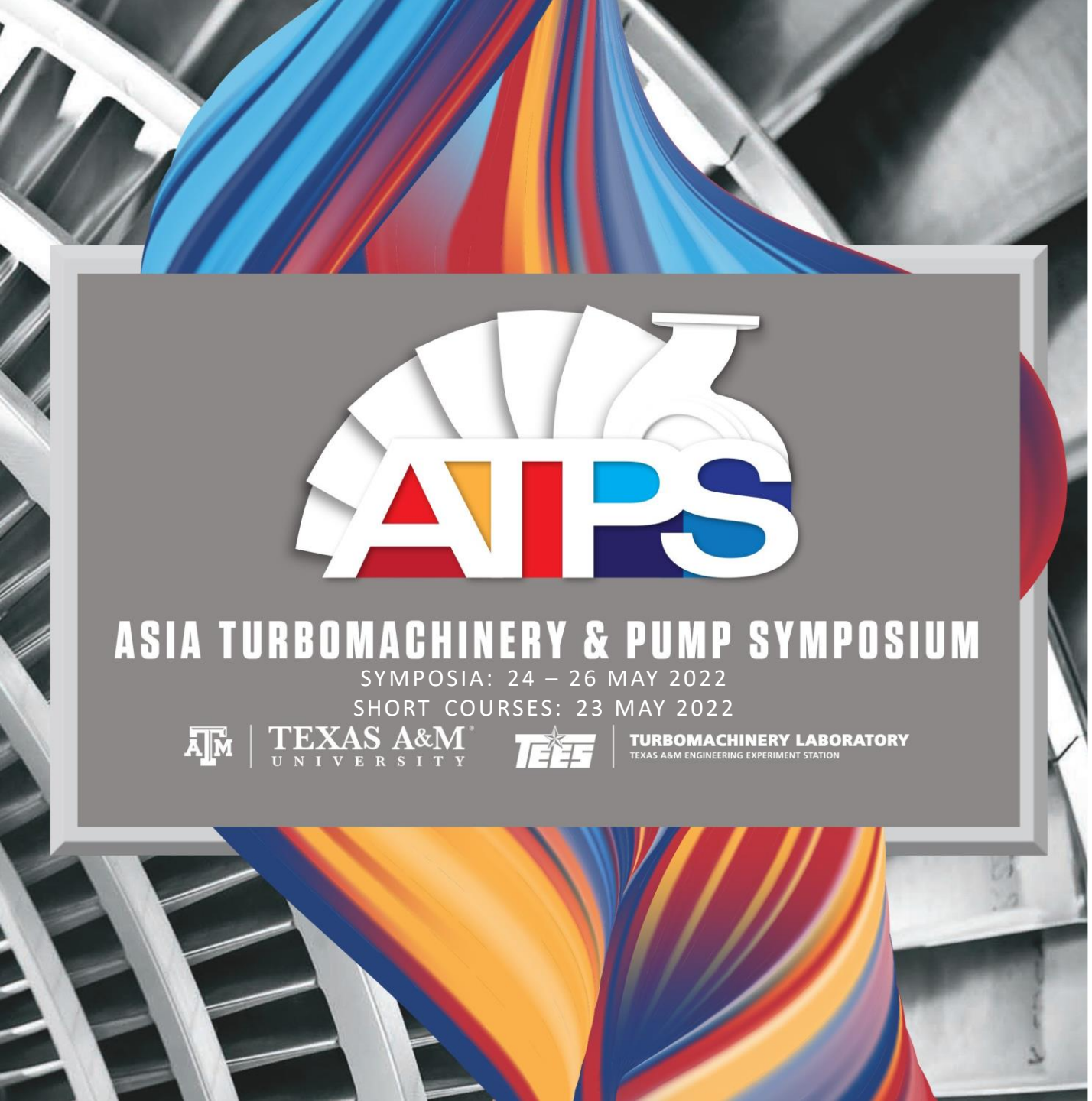



# Vibration issue on Compressor in a Nitric Acid Plant (Part 2)

Gary Wright – Bently Nevada
Nicolas Peton – Bently Nevada
Sergey Drygin – Bently Nevada
John Yu – Bently Nevada
Dave Davies – Orica

# Presenter / Author bios

**Nicolas Peton, Global Director - Machinery Diagnostics Services**

Nicolas joined Bently Nevada Machinery Diagnostic Services (MDS) group in 2006 and is currently the Machinery Diagnostic Services teams Global Director. Previously he worked for Alstom Steam turbine and Cryostar expander/compressor and was responsible for all site-based start-up activities worldwide. He also worked as an operation and maintenance engineer in the chemical industry (PPG industry, USA) and as Free Lance for startup activities worldwide. He was a mechanical/acoustical research engineer in research institutes (Technion, Haifa and TU Berlin). He has a Diplome d'ingénieur from the Université de Technologie de Compiègne, France.

**Sergey Drygin, PhD – MDS Technical Leader, Southern Europe**

Sergey is the Technical Leader for Bently Nevada Machinery Diagnostics Services for the Southern Europe region. He joined Bently Nevada in 2006 in the Machinery Diagnostic Services group and has 20+ years of experience in condition monitoring and machinery diagnostics on various types of industrial machinery as Senior Machinery Diagnostics Engineer. Sergey has a PhD. degree in Machinery and Technology, Engineer's and Bachelor's degrees from Faculty of Electro-mechanical Engineering, at Kuzbass State Technical University, Russia. Sergey is a certified trainer for Bently Nevada product and is CAT III certified expert from Russian Society of NDT Certification.

**Dr. John Yu  PhD, MDS Global Technical Leader**

John joined Bently Rotor Dynamics Research Corporation in 1998, followed by General Electric - Bently Nevada in 2002. He has performed not only rotor dynamic research but also machinery vibration diagnostics for customers worldwide and is now Global Technical Leader of Machinery Diagnostic Services at Bently Nevada. He has over 50 technical papers in peer-reviewed journals and conference proceedings. He holds a PhD in Mechanical Engineering from University of Alberta and is an ASME Fellow. He currently serves as an Advisory Committee member to the Asia Turbomachinery & Pump Symposium.

**Gary Wright, MDS Technical Lead Offline Data**

Gary is the Machinery Diagnostics Services Offline Technical Lead based in Adelaide, South Australia. He joined Bently Nevada in 2011 as an MDS Engineer performing machinery diagnostics on various types of industrial machinery. He has 30+ years of experience in condition monitoring at both onshore and offshore locations being originally based in Aberdeen, Scotland. He is an ex balancing machine operator and motor/generator repairer/installer and has extensive vibration acceptance testing experience. He is an ISO Category 4 certified vibration analyst as well as a VCAT 2 certified oil analyst.

**David Davies, Integrity Specialist – Machines (Orica Manufacturing Australia)**

Dave is a machinery specialist working for the Orica Global engineering Group and is based out of the the Kooragang Island (KIW) Ammonium Nitrate manufacturing facility, Newcastle NSW. Dave has been with Orica for over 35 years across various sites with 25+ years of experience in rotating machinery maintenance and condition monitoring. He has an associate diploma in mechanical engineering.

# Abstract


“Part 1” of the case history for this return to service follows on from the 2021 ATPS “virtual” presentation which covered off the Expander related issue (labyrinth seal rubs) preventing the NAP2 plant from successfully re-starting. “Part 2” covers off the machinery issues encountered during the following twelve-month period of operation.

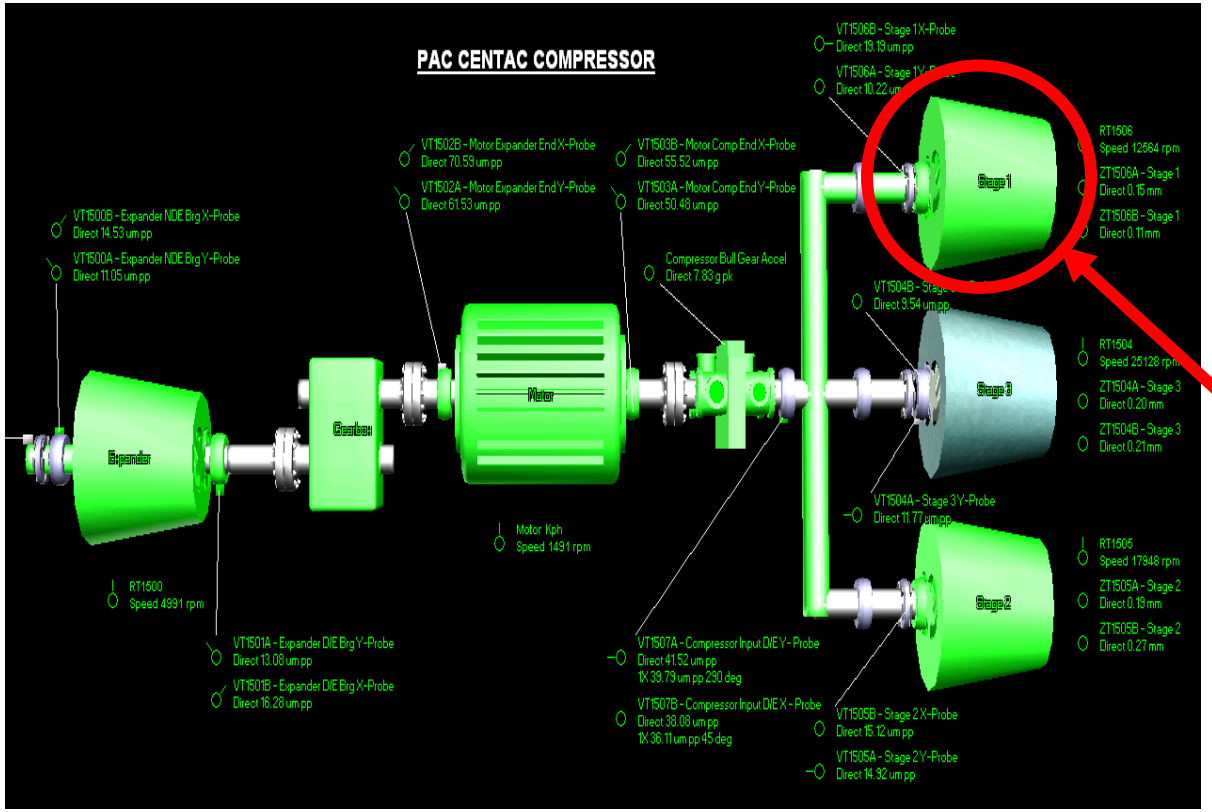
The NAP2 PAC was completely overhauled in March/April 2019 during a scheduled turn-around period, conducted every 5 years, inclusive of a motor rotor replacement, step-up gearbox overhaul, a new air end compressor installation as well as hot gas expander thrust bearing and thrust collar replacements/repairs. Additionally, the expander seals were replaced with like-for-like but tighter clearance carbon seals, the entire drive train was re-aligned and a new anti-surge valve was installed.

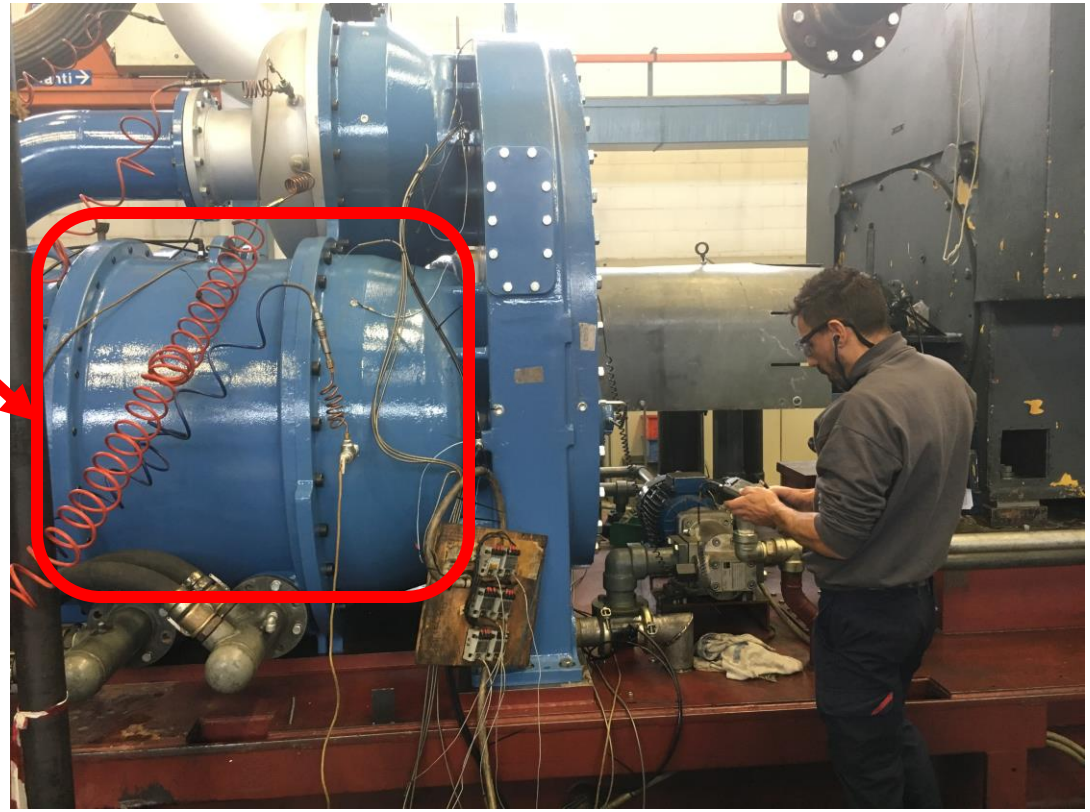
During bi-monthly remote diagnostics review as part of an SSA agreement (6x annual remote diagnostic reviews of all steady state and transient vibration data) it was verified that the NAP2 PAC would occasionally trip off-line due to high compressor 1$^{st}$ stage direct (overall) & 1x synchronous vibration during steady state operation. Diagnosis verified compressor 1$^{st}$ stage rub (trip) events during steady state operation as well as occasional stall and/or surge events due to anti-surge system issues during shutdowns. Additionally, a prominent 1$^{st}$ stage -3x reverse vibration component manifested post the turn-around with increasing amplitudes up until the OEM attended site to perform a repair in (February 2020).


ATPS
ASIA TURBOMACHINERY & PUMP SYMPOSIUM

# Part 1 - 2021 “Virtual” Presentation

# NAP2 PAC at OEM Facility/S1 View



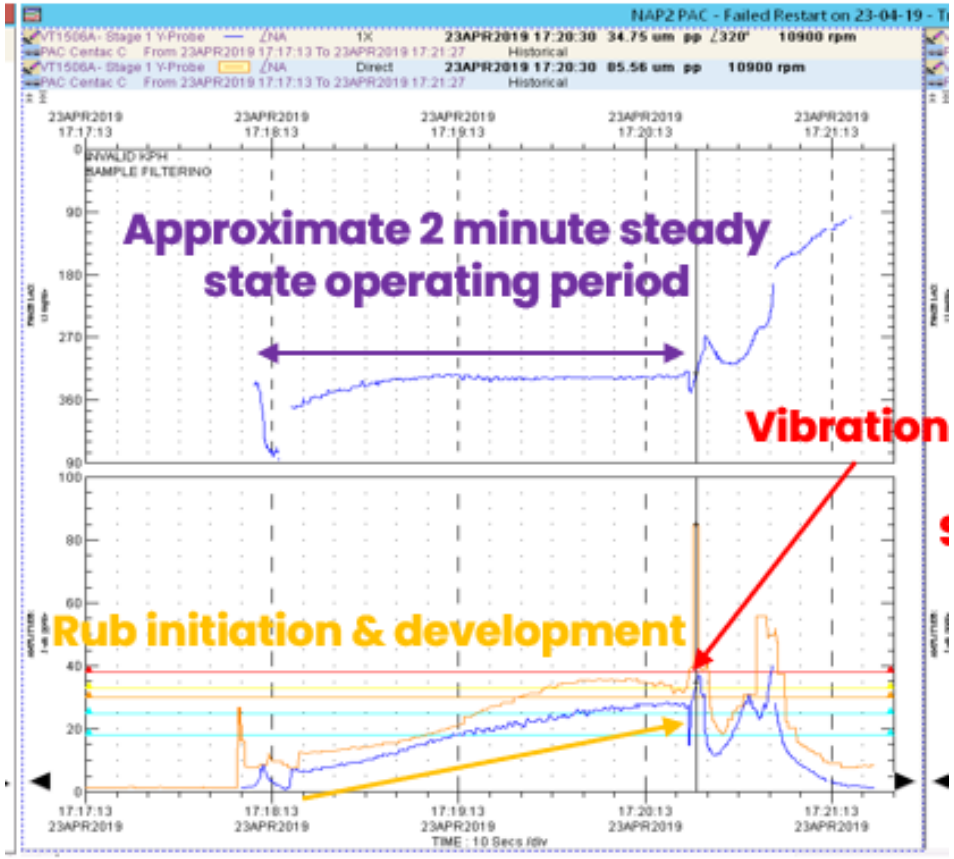



ASIA TURBOMACHINERY & PUMP SYMPOSIUM

# Problem Statement

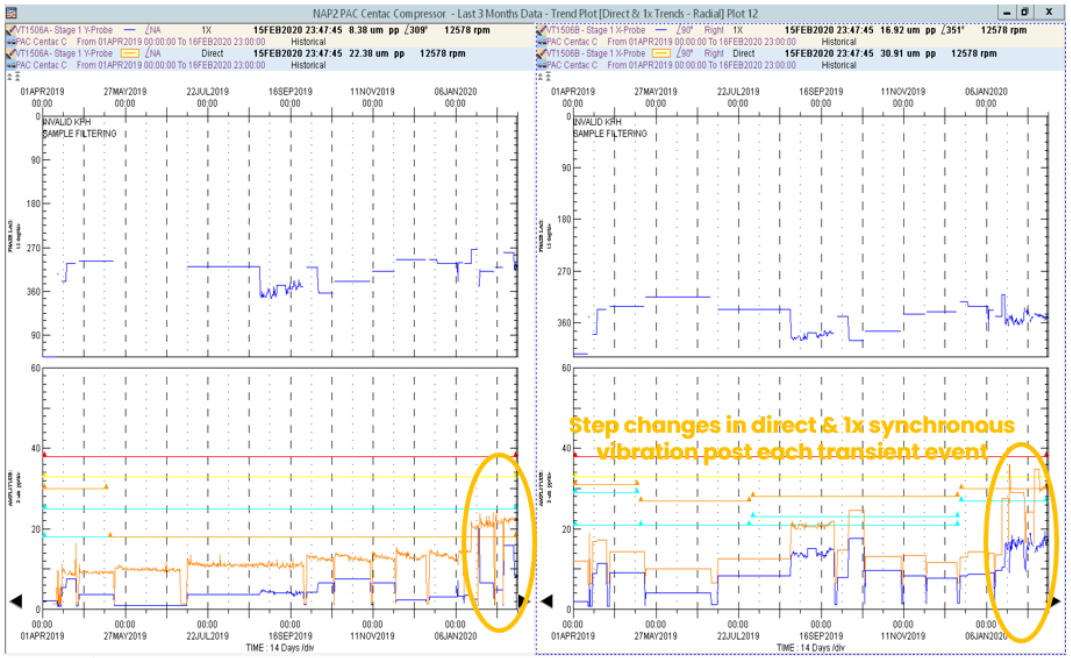
- The NAP2 PAC drive train was completely overhauled during a once-every-five–years turn-around period inclusive of the installation of a completely new air end compressor.
- Shortly after the turn-around re-start and due to a process related issue, the compressor was shutdown which resulted in a significant 1st stage surge event.
- During the subsequent (within 3 hours) re-start the compressor tripped off-line (within 2 minutes of reaching steady state operation) due to high compressor 1st stage direct & 1x synchronous vibration associated with a rub condition.
- During the next twelve-month operating period, the NAP2 PAC experienced numerous additional 1st stage rubs during steady state operation, as well as occasional 1st stage stall and/or surge events during shutdowns.
- Additionally, a prominent 1st stage -3x reverse vibration component manifested post the turn-around with increasing amplitudes up until the OEM attended site to perform a repair in (February 2020).

# Data & Analyses – Rub Plots (23-04-19)




- On 23-04-19 the NAP2 plant was shutdown due to a plant process related issue. During the subsequent re-start (approx. 3 hours later) 1st stage direct & 1x synchronous trend plots (above right) verified a rub event which was initiated immediately after reaching full operating speed with the OEM Danger (Severity 4) trip set-point breached @ approx. 17:20:27, 2 minutes after the re-start.
- During the subsequent shutdown vibration related trip event the compressor 1st stage experienced two stall events @ approx. 11,350 rpm and approx. 5,600 & 4,300 rpm.

# Data & Analyses – Long-Term Trends




- The compressor 1st stage direct & 1x synchronous long-term trend plots verify a series of step changes in direct values post each shutdown transient event associated with increasing -3X reverse component vibration with amplitudes as high as 14 um pp measured on February 6th 2020.
- 1X synchronous trended values were also noted as being variable post each shutdown transient event as well as during steady state operation.
- Direct values became highly variable in January 2020 breaching the OEM Alert value of 33 um pp, but remaining marginally below the Danger (trip) set-point of 38 um pp.

# Data & Analyses – 1st stage Run-Out

The periodicity of such irregularities observed by the XY proximity probes, different combinations of forward and reverse components are observed. The rules for such an analysis are summarized below.

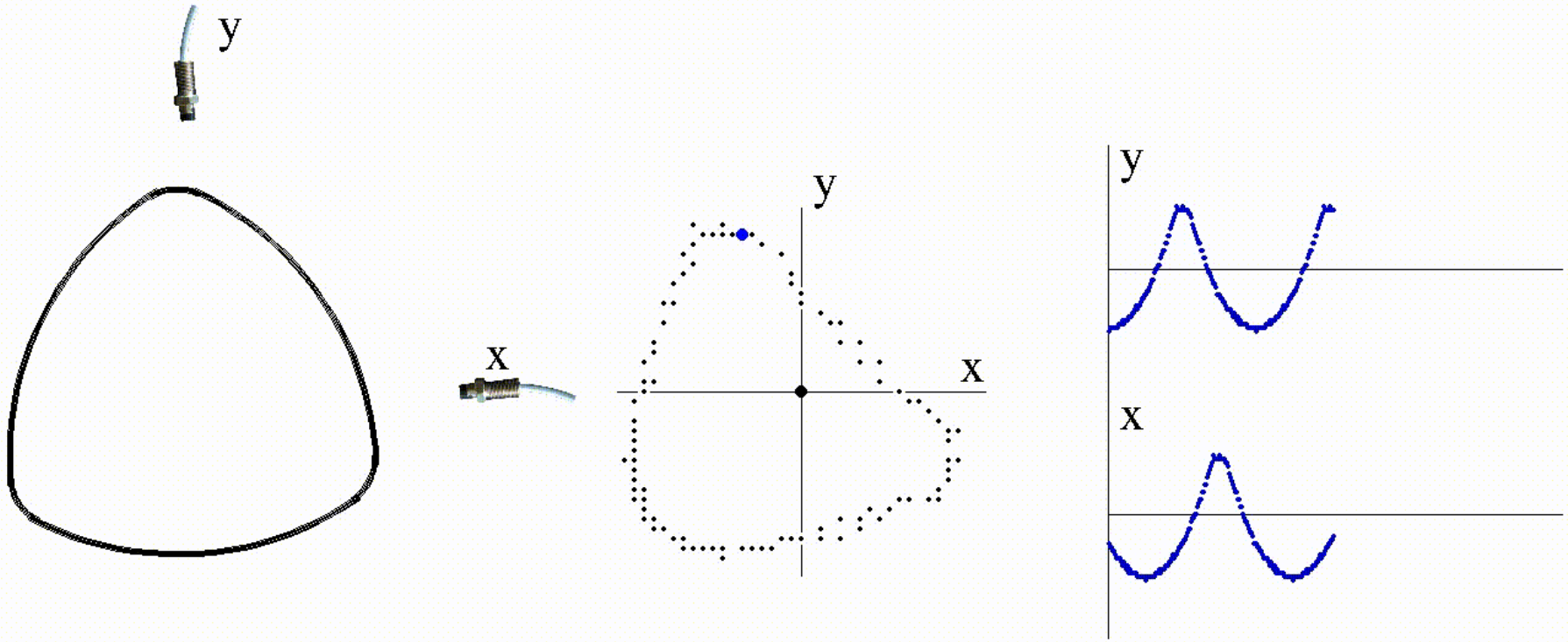
| Periodicity of irregularities | Once per cycle | Twice per cycle | Three times per cycle | Four times per cycle | Five times per cycle |
|---|---|---|---|---|---|
| **Major frequency components** | 1X forward (can include mechanical bow) | 2X forward and 2X reverse, with the same magnitudes | 3X reverse | 4X forward and 4X reverse, with the same magnitudes | 5X forward |

The *constant amplitude* -3x reverse component vibration measured throughout the entire speed range during each of the NAP2 PAC shutdown transient events specifically relates to *run-out measured at the probe-tracking region of the 1st stage journal, rather than a rotor dynamic issue.* However, Bently Nevada deemed that the increasing 1st stage run-out (increasing -3x reverse component amplitudes post each shutdown transient event) was ***an indication of a defect progression specifically associated with the impeller to journal fit.***

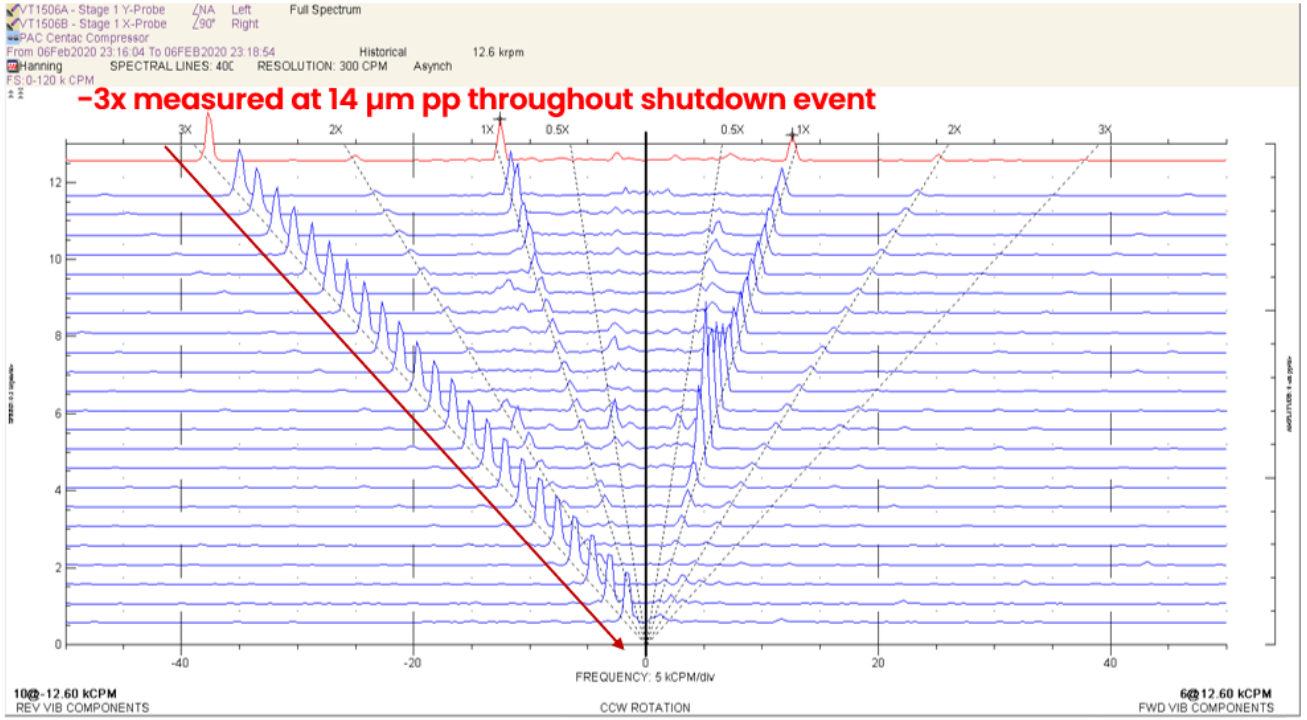
**Table 1 –Runout Signature Analysis, Bently Nevada Orbit Magazine Article 1999 - Application of full spectrum to rotating machinery diagnostics (Paul Goldman Ph.D. & Dr Agnes Muszynska Ph.D.).**

# Data & Analyses – 1st stage Run-Out

## 3x Reverse precession simulation



# Data & Analyses – 1st stage Run-Out




- The February 6th 2020 shutdown was the last shutdown transient event prior to the OEM site based repair at the end of that month. The Compressor 1st stage full spectrum cascade plot indicates -3X reverse component vibration measured in the region of 14 um pp throughout the Feb 6th 2020 shutdown.
- 1x synchronous reverse vibration amplitudes are also higher than the forward components, the exception being as the rotor transitioned the 1st (translational) critical speed range.
- The -3X reverse component indicated a compromised fit between the impeller bore and the rotor journal (tapered polygon P3 design) resulting in journal deflection during steady state and transient operation.

# Maintenance Findings

We were informed of the following site-based maintenance findings (Mid-February 2020) and subsequent repair work;

- 1st stage tilting pad bearing indicated signs of heavy rub on the bottom two pad edges.
- 1st stage cylindrical bearing indicated signs of rub at the top of the bearing and heavier at one end.
- 1st stage impeller bore indicated evidence of anti-cease/slip compound used during the impeller installation at the OEM factory in Italy**.**
- 1st stage tilting pad bearing replaced.
- 1st stage cylindrical (outboard) bearing replaced.
- 1st stage impeller was slow-speed balanced (dedicated shop balancing machine - in a low-speed balancing machine).

The shop balanced original impeller was re-installed onto the 1st stage rotor journal as per OEM specifications *with no anti-seize/slip compound applied.*

# Maintenance Findings

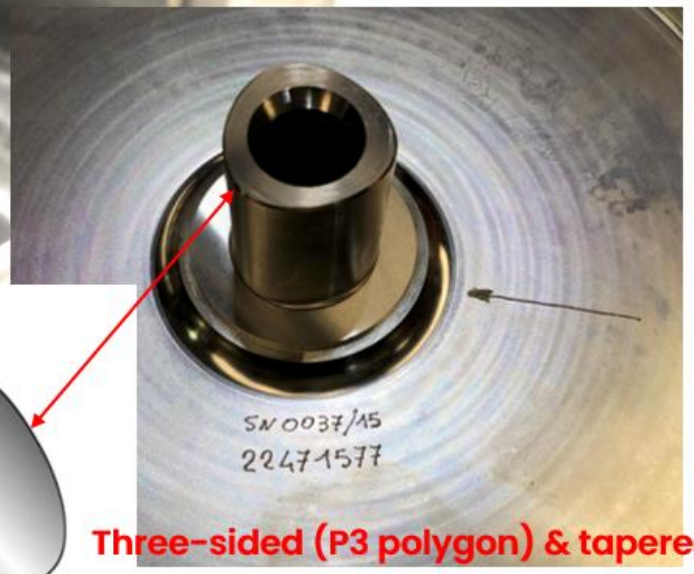
Thereafter, compressor 1st stage direct & 1x synchronous vibration has remained steady up to the presentation compilation date (30th January 2022) with no compressor 1st stage surge, rub events or increasing -3x component vibration amplitudes.

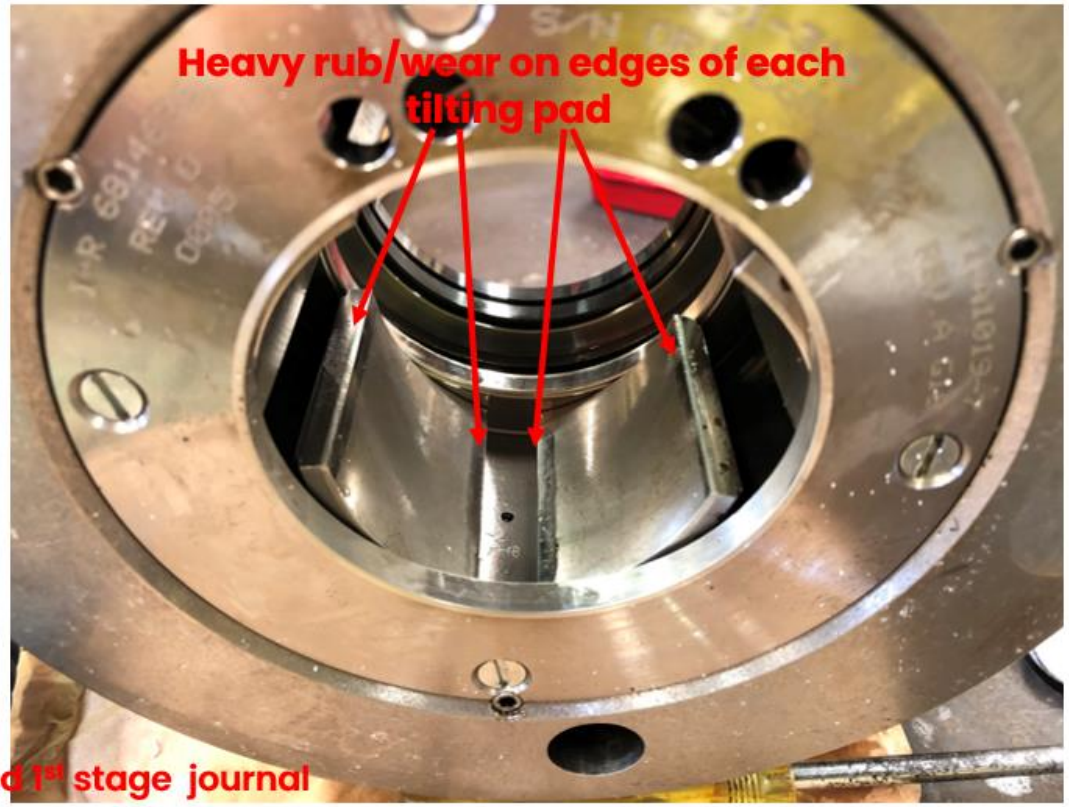
We were informed of the following OEM off-site root cause analysis findings (nearly 12 months post the site visit),

- ***1st stage tilting pad & cylindrical bearings were supplied with incorrect dimensions,*** radial bearing clearances are *not checked* by OEM prior to installation (mandrel checks) with only the thrust bearing end float checked/verified.

# Maintenance Findings

The digital photograph of 3-sided impeller bore of the compressor 1st stage impeller with the shaft fit compound evident.

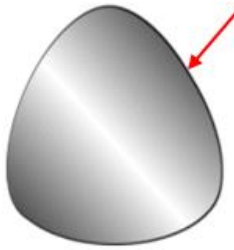


Heavy rub/wear on edges of each tilting pad

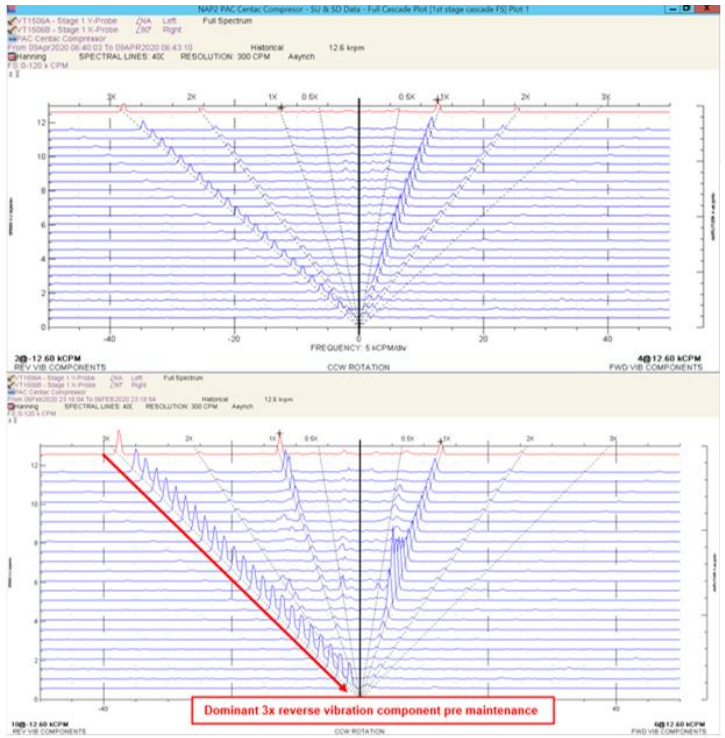
- **P3 Profile**

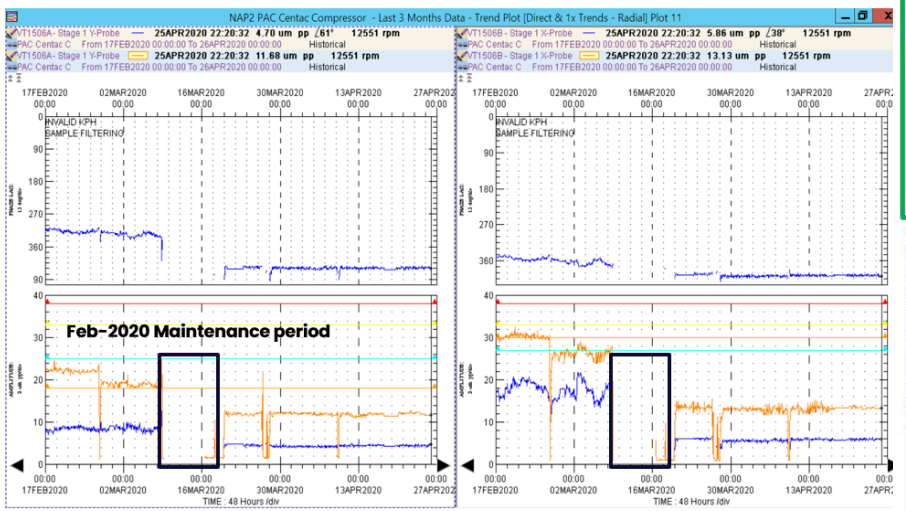
P3 profile has a three sided configuration. This polygon profile is used in cases where the female profile of the polygonal connection must be ground, and also for tapered profiles. With this polygon profile the female hub can be finished ground on the machine for a highly precision fit. P3 profile is ideal for **high torque** and **high stress** applications.

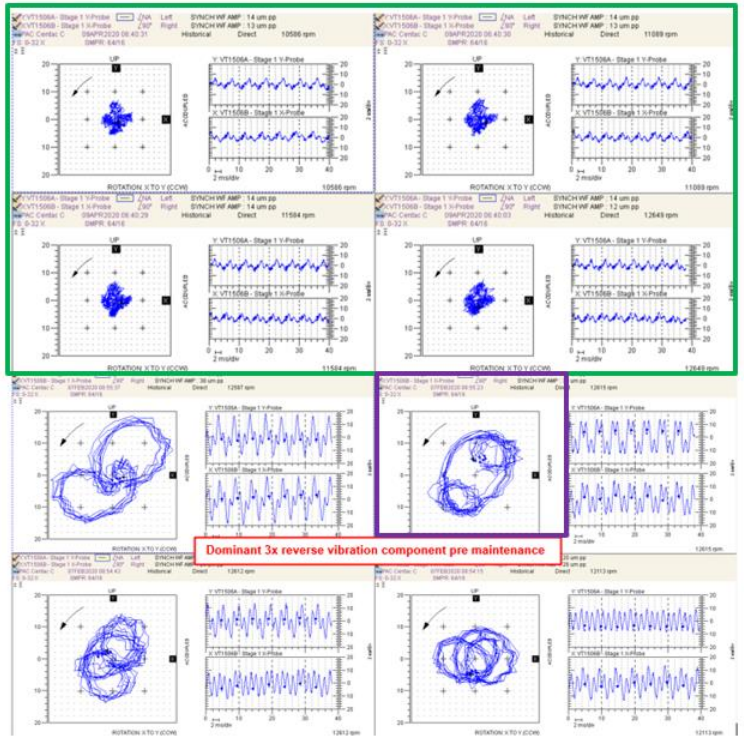


Three-sided (P3 polygon) & tapered 1st stage journal

# Pre/Post Repair 1st Stage Data




- Post the repair there was a step decrease in compressor 1st stage direct & 1x synchronous values with direct values now trending well below the OEM Alert set-point of 33 µm.
- The decrease in compressor 1st stage direct values is attributed to decreases in the amplitudes of the previously dominant 1x & -3x 1st stage frequencies (12,558 rpm rotor).
- Post the repair;  full spectrum asynchronous cascade plot verifies a reduction in 1x synchronous forward vibration amplitudes during steady state operation as well as during transient events (transitioning of the 1st/translational balance resonance).

# Results Realized

- Through ongoing diagnostic evaluations (bi-monthly assessments) of the post turn-around NAP2 PAC Compressor steady state and transient vibration data, all developing machinery related malfunctions were diagnosed and reported to the client at the earliest opportunity and within the warranty period.
- As the various machinery issues were diagnosed early (post the overhaul) and routinely tracked for any further progression, the plant was still able to continue to operate at full capacity until the OEM scheduled a site-based repair that was scheduled to fall within the 12-month warranty period.
- Diagnostic evaluations gave the required guidance to the OEM (via the client) to ensure a full, comprehensive and ultimately successful repair was performed, inclusive of impeller removal (this work was *not* part of the original OEM repair scope but on advice the integrity of the fit for 3-sided polygon impeller to journal fit was verified).
- After the 1st stage surge, rub and impeller to journal fit related issues were resolved by the OEM; the client was able to successfully restart the NAP2 PAC compressor, under diagnostic supervision, with no further machinery related malfunctions to report up to the present day.

# Lessons learned

- Persistent investigation into plausible sources of the increasing -3x reverse component vibration amplitudes associated with run-out continued until the OEM eventually confirmed the 3-sided polygon journal to impeller bore fit/design, which eventuated as being the root cause of one the three vibration issues.
- -3x reverse component vibration with steady amplitudes throughout the speed range during shutdown transient events was verified as a specific type of run-out, rather than a rotor dynamic issue, though the increasing amplitudes (increasing run-out) measured during consecutive shutdowns was deemed indicative of an underlying machinery issue (compromised impeller to rotor fit).
- On high-speed compressor stages the fit between the impeller and rotor/journal (three sided P3 polygon/tapered design) can be compromised by the application of anti-cease type products/compounds.
- Surge conditions can initiate secondary machinery issues, in this case rub related vibration trip events.
- Rubs, which typically occur at the locations of least clearance, can also occur internal to cylindrical and tilting pad design bearings especially if the installed bearing clearances are undersize (too tight).
- Radial bearing clearances should always be verified (mandrel check).