A Sub-Synchronous Vibration Problem:

Trapped Fluid in Compressor Coupling Spacer

Diagnosis and Resolution

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Compressor Vibration Problem

The Recovery Gas Compressor on a new offshore gas platform would run for only a short time before developing vibration in the driven end shaft bearing, near the coupling to the power turbine.

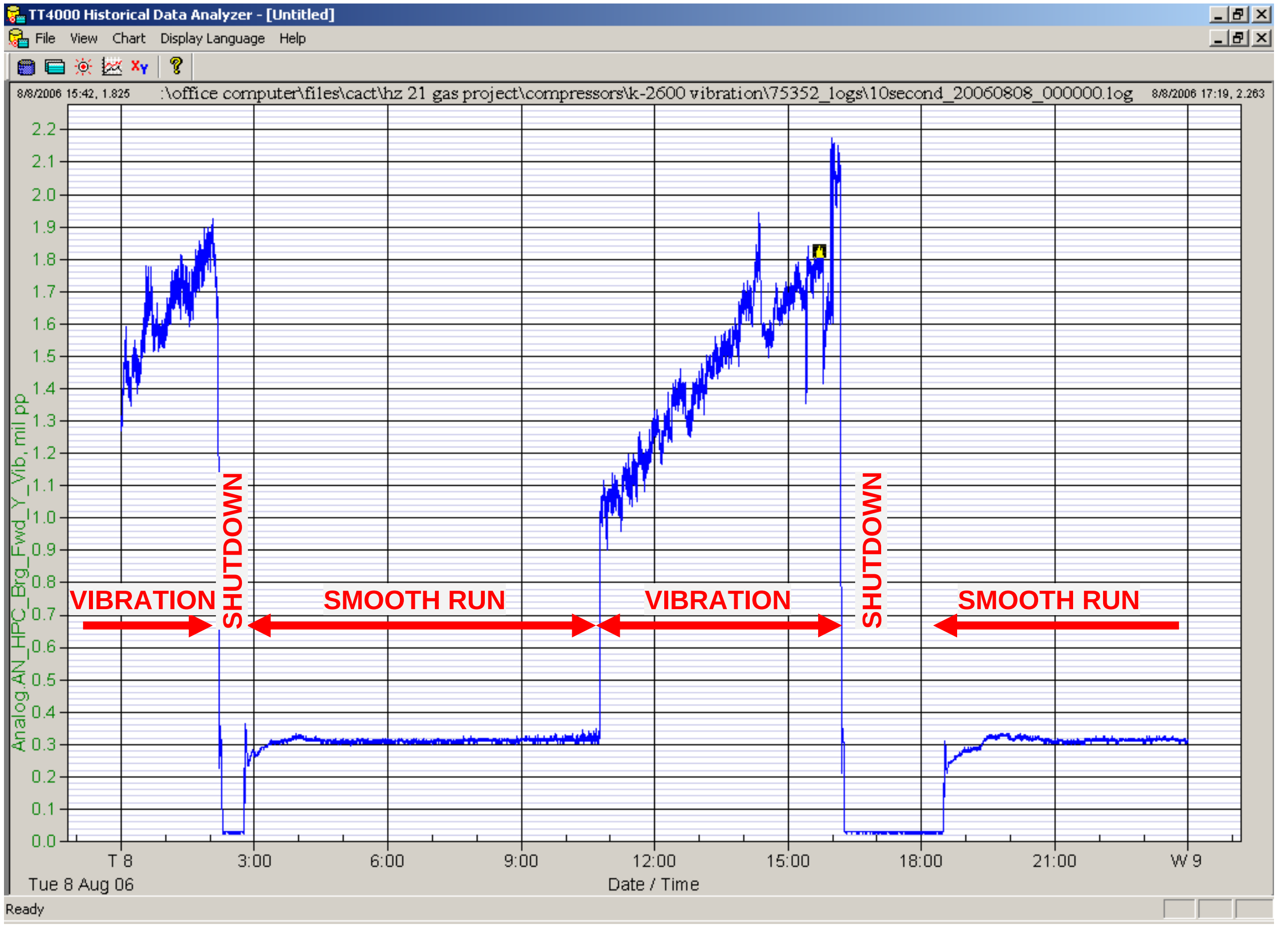
After the vibration started, it would gradually increase over the next several hours until reaching the limit to cause compressor shutdown. After a short shutdown (~1 hr), the compressor would be restarted and the cycle repeated.

Initial investigation by the vendor reported that the vibration was not mechanical in nature.

The vibration was sub-synchronous, with a vibration frequency at 93% of compressor operating speed.

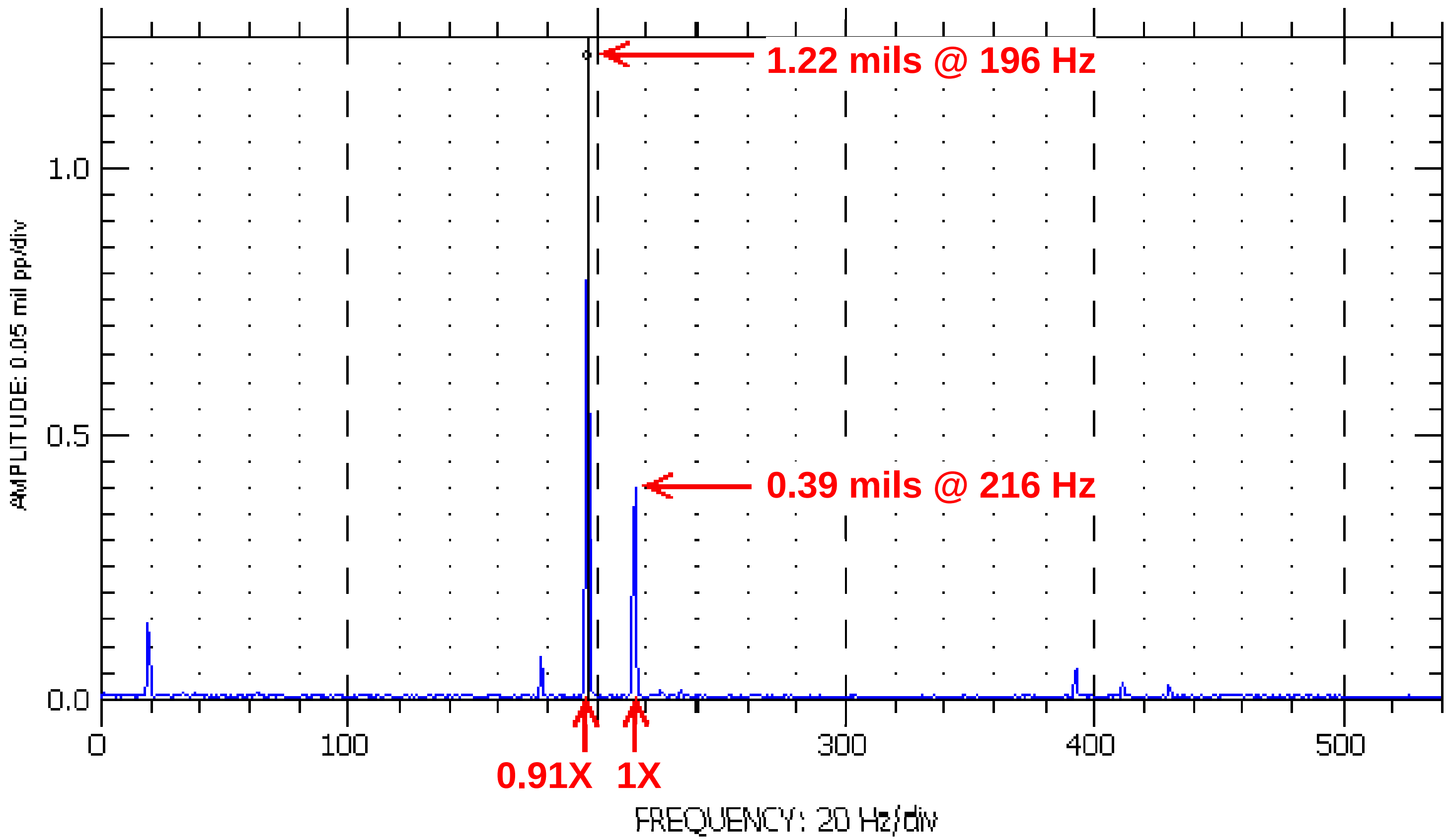
Compressor Location

Characteristic Vibration Curve



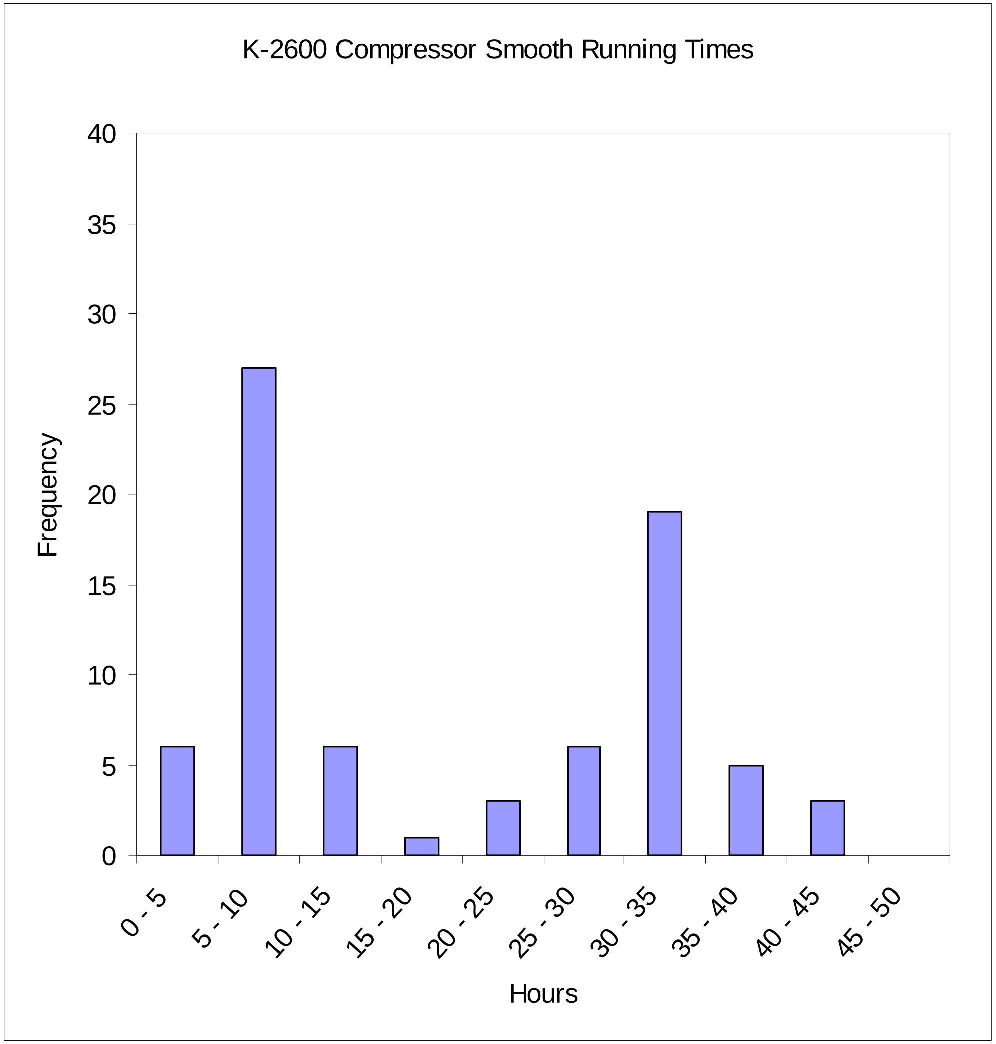
- Vibration was in compressor driven end only, not non-driven end.
- Turbine driver is not fitted with vibration probes.

Vibration Spectrum



Smooth Run Times

The compressor would usually run smoothly either about 10 hours or 30 hours before onset of vibration.



Key Technical Questions

- What could cause the vibration to crop up after 10 or 30 hours of smooth run time? If this were a mechanical problem, the vibration would occur within two hours when the compressor reached thermal equilibrium.

- Why would the cycle start again after a shut-down of at least 45 minutes and allow another 10 or 30 hour run, but after a shorter shutdown the vibration would return almost immediately?

- What could cause the vibration to "ramp up" (increase) in magnitude once it cropped up?

- What could be the cause of vibration that was not a function of turbine speed or compressor flow rate?

Focus #1 – Suction Scrubber

Liquid carryover from suction scrubber

- Poor scrubber design could allow for buildup of liquids in mist extractor section in 10-30 hours.
- Poor scrubber design could allow for buildup of foam within scrubber in 10-30 hours.
- Scrubber had additional design problems

Action:

- Replaced scrubber inlet deflector
- Replaced scrubber mist extractor

Result:

- Increase in liquid recovery of scrubber
- Significant reduction in liquid carryover
- No effect on vibration.

Focus #2 – Gas MW

Molecular weight of gas affects compressor performance

- Possible accumulation and recycle of condensate in process causes change in MW over 10-30 hours.
- Compressor may vibrate if MW is greatly different from design specification.

Action:

- Sample and test MW at various times and conditions.
- Evaluate compressor design for operation within range of MW.

Result:

- Tests inconclusive. Confirmed that MW change will affect performance, but unlikely to cause vibration.

Focus #3 – Seal Gas

Liquids in seal gas

- Compressor seals require liquid-free seal gas, but this compressor had liquids in seal gas.
- Liquids in seal gas could accumulate in 10-30 hours and cause vibration in the seal (seal chatter).

Action:

- Supply seal gas from fuel gas system.

Result:

- Very dry seal gas, but no change in vibration

Focus #4 – Air in Lube Oil

Air build-up in lube oil system

- Lube oil pump is on vacuum, so air could be drawn in over 10-30 hours.
- Air in bearing could cause localized cooling coincident with vibration (observed phenomenon).

Action:

- Ascertained integrity of lube oil pump suction piping.
- Sampled lube oil at various times and conditions.
- Replaced ISO 32 lube oil with ISO 46

Result:

- Lube oil air bubbles appeared same regardless of vibration status, and also same as in other turbines operating normally
- Lube oil viscosity change resulted in minor differences in vibration.

Focus #5 – Aerodynamics and Resonance

System resonance can cause vibration

- Harmonic resonance or aerodynamic effects within the process piping or within the compressor itself could excite vibration.

Action:

- Fitted high frequency dynamic pressure transducers on piping and compressor for Fast Fourier Transformation (FFT) analysis.

Result:

- Piping resonance is not present.
- Ruled out aerodynamic influence (e.g., compressor stall) as possible cause. There is a small pressure pulse within the compressor at the vibration frequency that may excite and exacerbate the vibration problem.

Focus #6 – Lube Oil Outside Coupling

Excessive lube oil outside coupling could cause viscous drag.

- Observed large volume of lube oil entering coupling housing from turbine bearing.
- Whirling oil/air mixture could build in density and viscosity over 10-30 hours, causing vibration from viscous drag.

Action:

- Removed and re-seated coupling hub to try to block excess oil.

Result:

- No significant reduction in oil volume. Oil volume not considered excessive. No impact on vibration.

Focus #7 – Lube Oil Inside Coupling

Lube oil inside coupling

- Spinning coupling creates internal vacuum to draw oil inside.
- Trapped oil spins at slightly slower speed than compressor speed due to viscous drag.
- Trapped oil accumulates over 10-30 hours to point where unbalanced mass causes vibration.

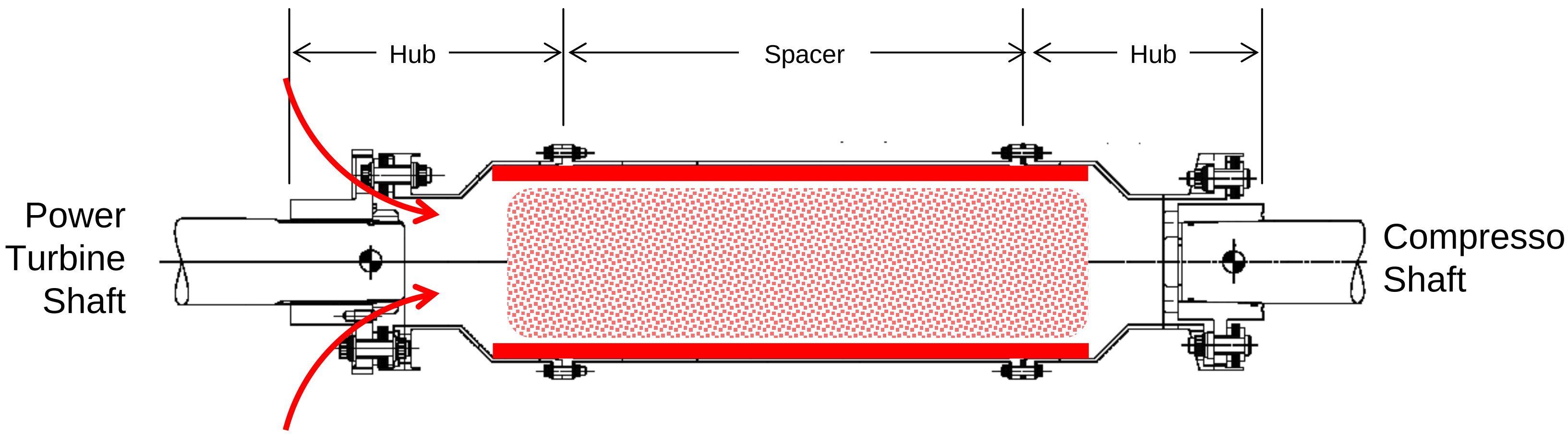
Action:

- Drilled 4 small weep holes to allow oil to be thrown out from within coupling.

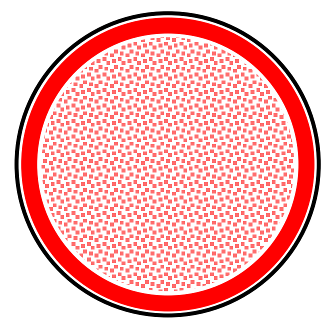
Result:

- Solved vibration problem.

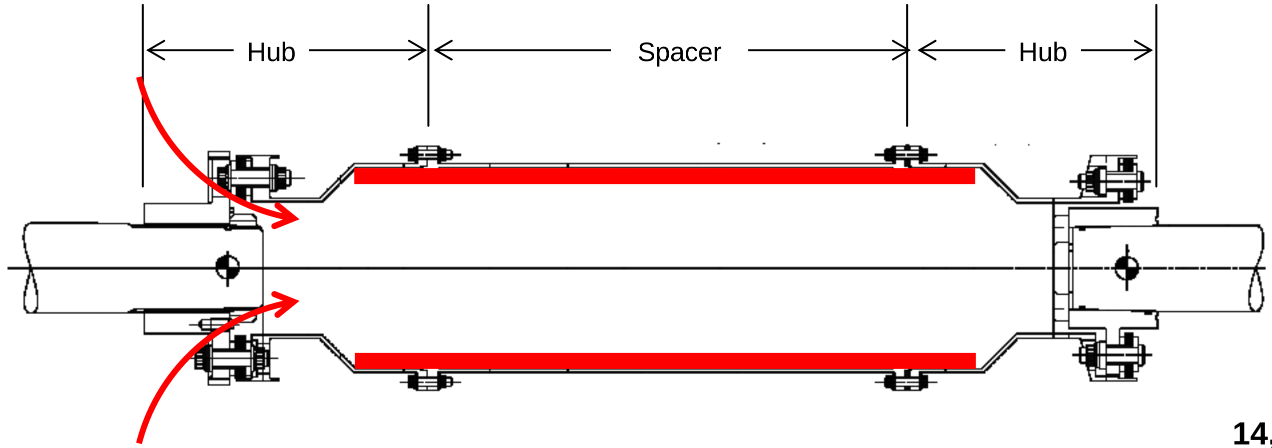
Compressor Coupling



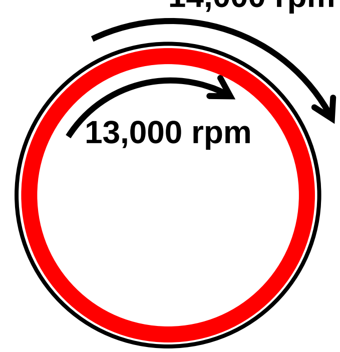
Lube oil is drawn into the spacer. As it rotates, the oil is trapped against the wall of the spacer. Spacer design has internal lip which prevented oil reaching existing weep holes in the end hubs.



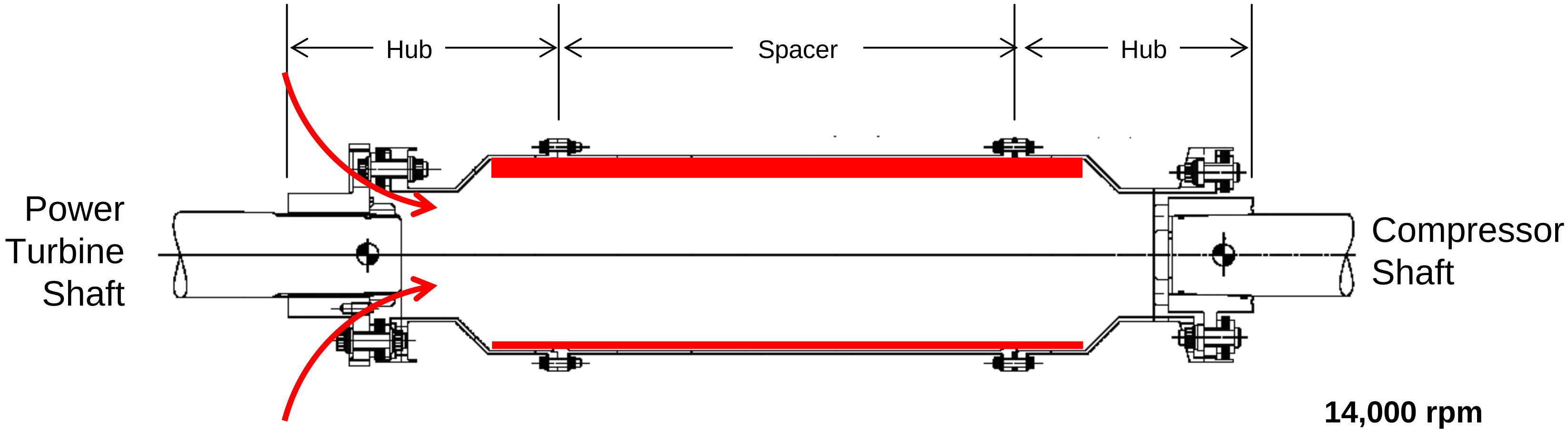
Compressor Coupling

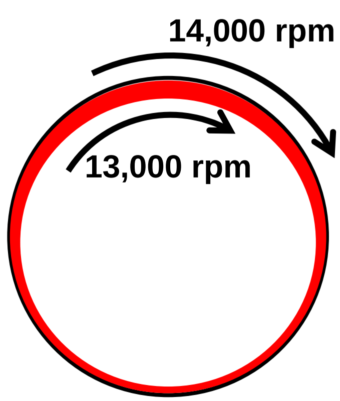


Because of viscous drag, the oil layer spins at a speed slightly less than the coupling speed (93% of compressor operating speed).



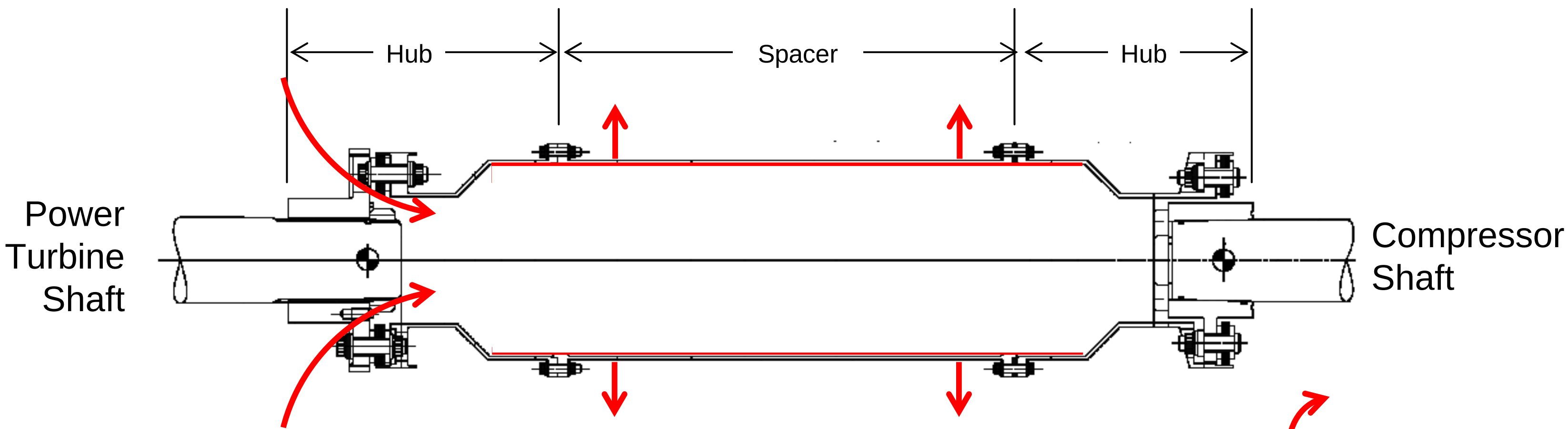
Compressor Coupling



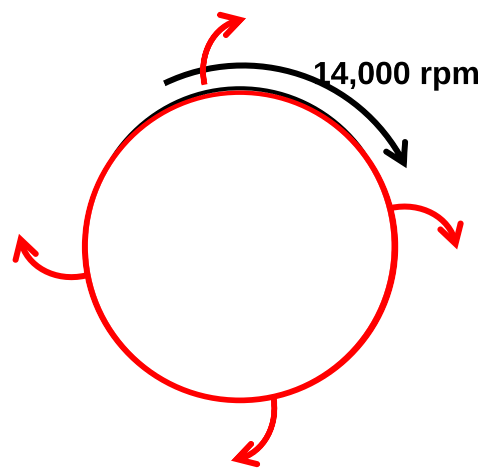


When the trapped oil layer builds up, the fluid distribution is unbalanced and vibration starts. As more oil enters, the distribution becomes more unbalanced and the vibration increases in magnitude, causing the “ramp up” feature of the vibration curve. The vibration is at 93% of compressor operating speed.

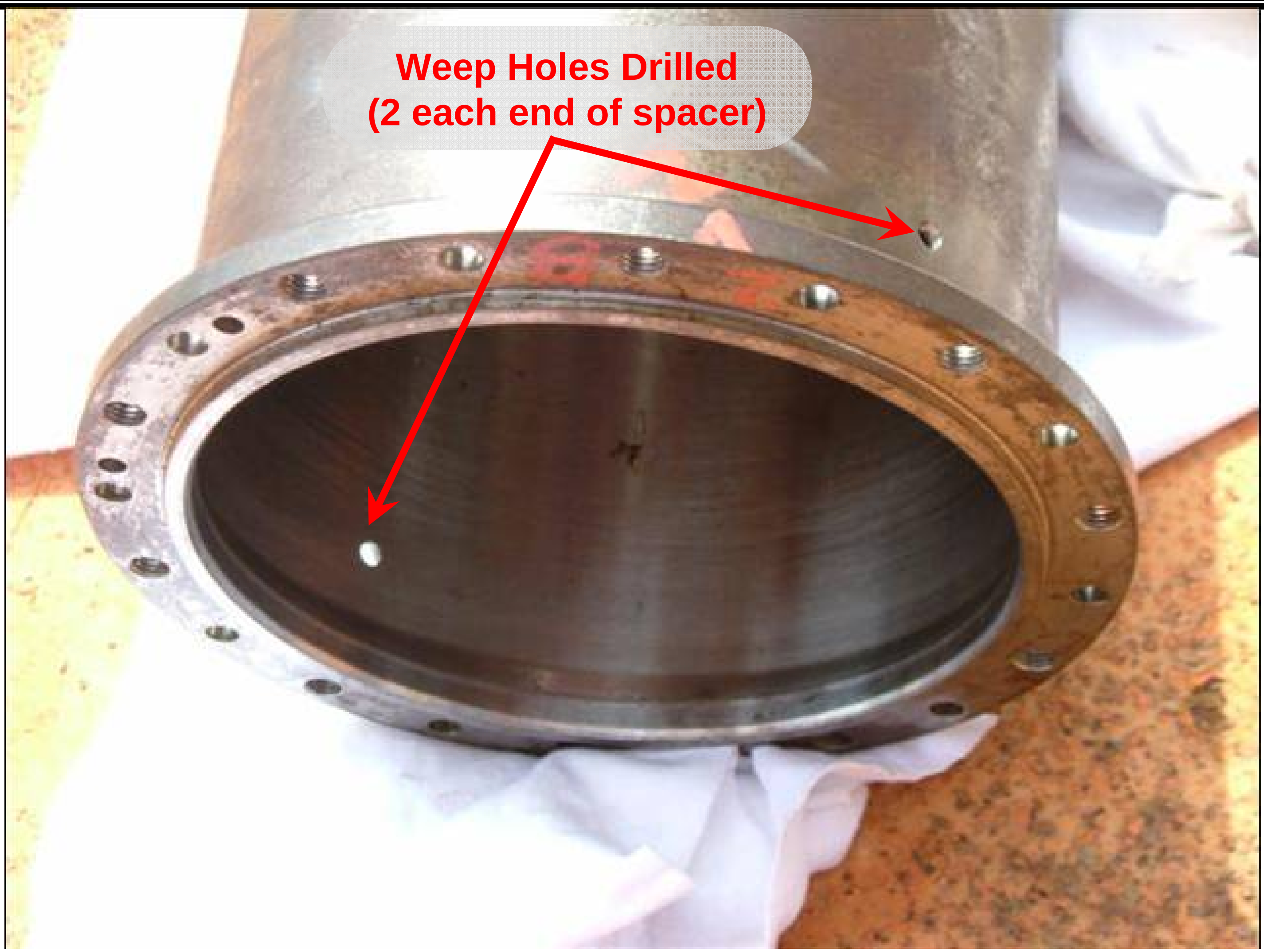
Compressor Coupling



Drilling 4 weep holes in the spacer allows the lube oil to escape, preventing the oil accumulation and consequent vibration. Oil returns to the lube oil tank through the coupling housing drain.



Coupling Spacer Weep Holes

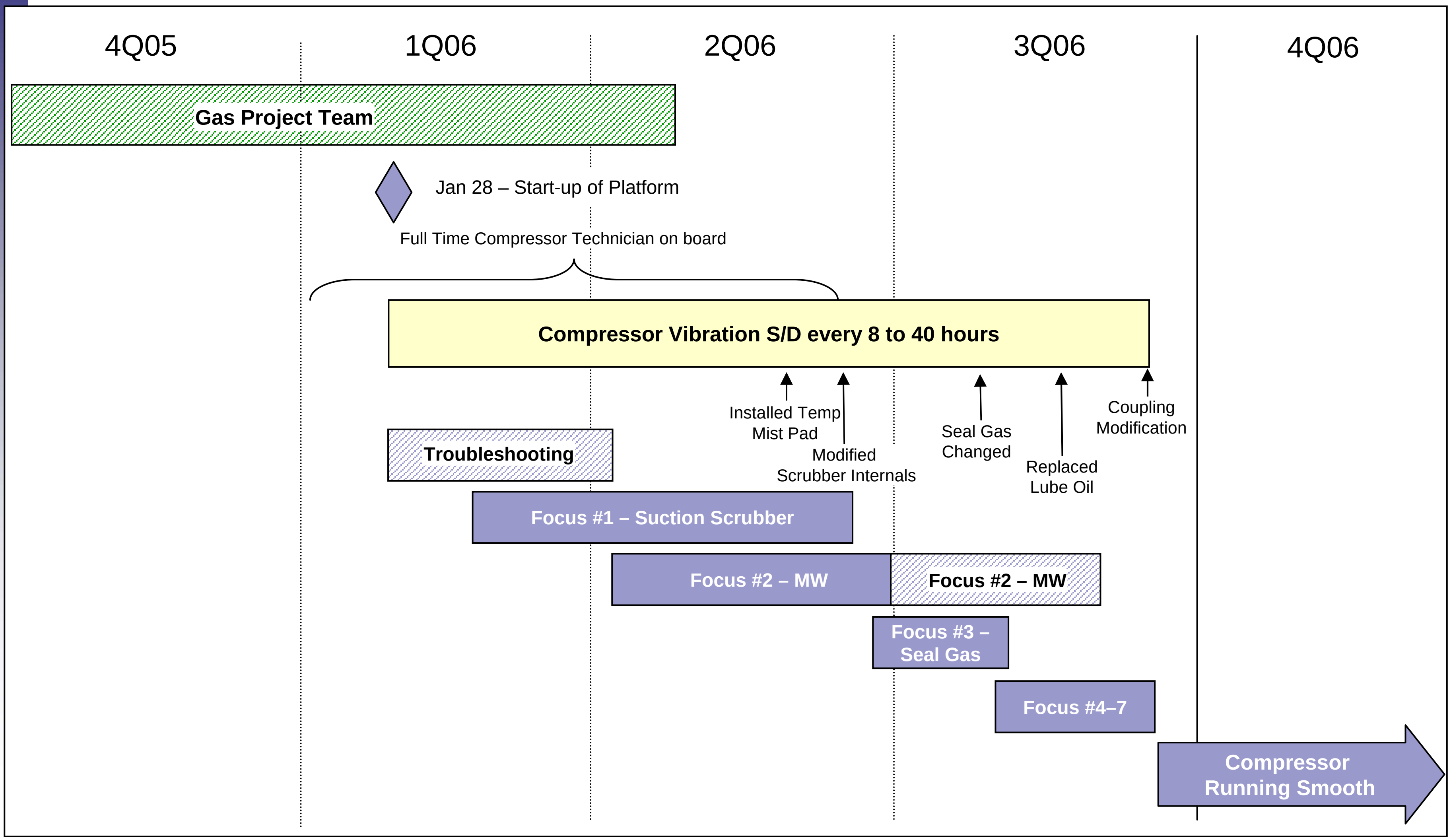


Compressor Vibration Problem

SOLVED!

Compressor running smoothly from 14 September 2006

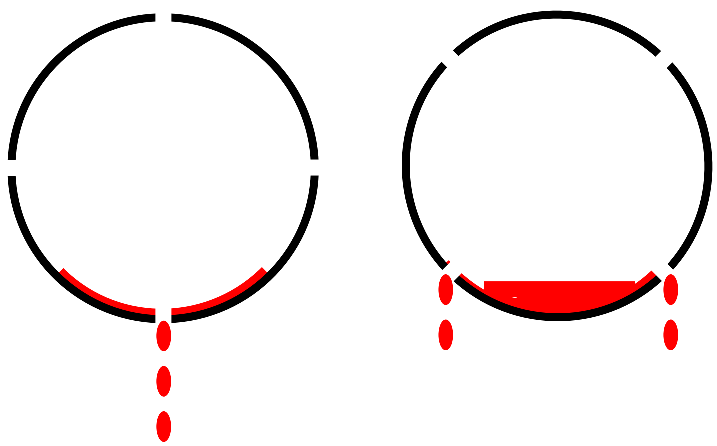
Compressor Vibration Timeline

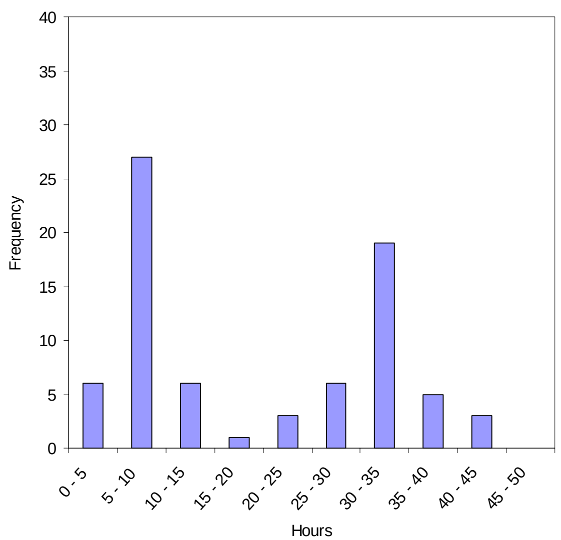


Why…..

Why did the unit generally run smoothly for either 10 hours or 30 hours before onset of vibration?

- There were existing weep holes in the coupling hubs, spaced at offset angles. If one of the holes was at or near the bottom of the coupling when it stopped, the oil would drain to the maximum extent possible, and the unit would subsequently run for about 30 hours. However, if none of the holes was at the bottom of the coupling when it stopped, the oil would only partially drain and the unit would subsequently run for only about 10 hours.





Why…..

If the unit was shut down for less than 30 minutes before re-starting, why did the vibration pattern recur almost immediately upon startup?

- The lube oil accumulated inside the coupling spacer did not have sufficient time to drain out through the lowest weep hole. The oil remaining in the coupling caused vibration soon after re-start.

Costs & Losses

Lost production

- Approx 1000 bopd for 6 months = 180,000 bbls.
- @ average price $65/bbl = $12 million lost revenue

Engineering

- Owner/Operator
  - Operations man-hours & costs – not quantified
  - Suction Scrubber Improvements – approx $130,000
  - Gas Sampling and Testing – approx $10,000
  - Seal Gas Supply Modification – approx $20,000
  - Work order spend approx $60,000
- Vendor / Manufacturer
  - Service Techs on site continuously 5 months – approx $150,000
  - Vibration analysis work order spend approx $50,000

Wear and Tear

- Turbine has over 140 starts in first 6 months of operation

Lessons Learned

Identify key data

- The significance of the subsynchronous nature of the vibration was not recognized in trying to identify potential causes.

Communication is vital, even if a minority view

- Several experts at different times discussed the possibility of oil in the coupling, but this was not communicated to the team in the field.
- The oil in coupling possibility was not pushed by those who brought it up because “everyone else” thought the cause lay elsewhere.

Address multiple issues simultaneously

- Methodical, one-at-a-time problem solving is suitable for academic work, but resolving all potential issues as quickly as possible is required when suffering expensive production losses.

Lessons Learned

Get the right experts involved

- Five people with 50% knowledge is no substitute for one person with pertinent experience.

Try to sort through the “red herrings”

- A number of issues were dealt with as the potential cause of the vibration, including liquids in the process gas and seal gas, air in the lube oil, piping resonance, etc. However in hindsight, none of these would have accounted for the subsynchronous nature of the vibration.
- This was a “textbook case” of sub-synchronous vibration caused by trapped fluid inside a rotating cavity. However, the other “likely causes” took precedence because they seemed to be more obvious.