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A SOLUTION TO YEARS OF HIGH VIBRATION PROBLEMS IN THREE REINJECTION COMPRESSOR TRAINS RUNNING AT 33 MPa DISCHARGE PRESSURE

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Abstract

Over a 13-year span, a major South American oil company's maintenance department fought **high vibrations in three gas reinjection compressor trains**. To reduce the chances of machine trips, technicians **field balanced** the compressors every year and **replaced** worn point contact pivot tilt pad journal (TPJ) **bearings** and O-ring **squeeze film dampers** (SFDs) with new ones **yearly**. The downtime from implementing these preventative measures and from actual trips in the trains resulted in a **loss of capacity** of 1% a year and additional flaring of the gas.

After a thorough analysis of the compressors and inspection of damaged components, it was determined that the reoccurring problems would be solved by installing optimized **Flexure Pivot** tilt pad journal bearings with **Integral Squeeze Film Damper** (**ISFD**) technology into the compressors.

In 2013 the reinjection compressors were placed back into service with Flexure Pivot TPJ bearings with ISFD technology. Since then the reinjection compressors have exhibited **lower vibration** levels that do not grow over time, have had **ZERO trips**, and have **not required field balancing** for continuous operation. Overall efficiency has **increased by** approximately **1%**.

Contents

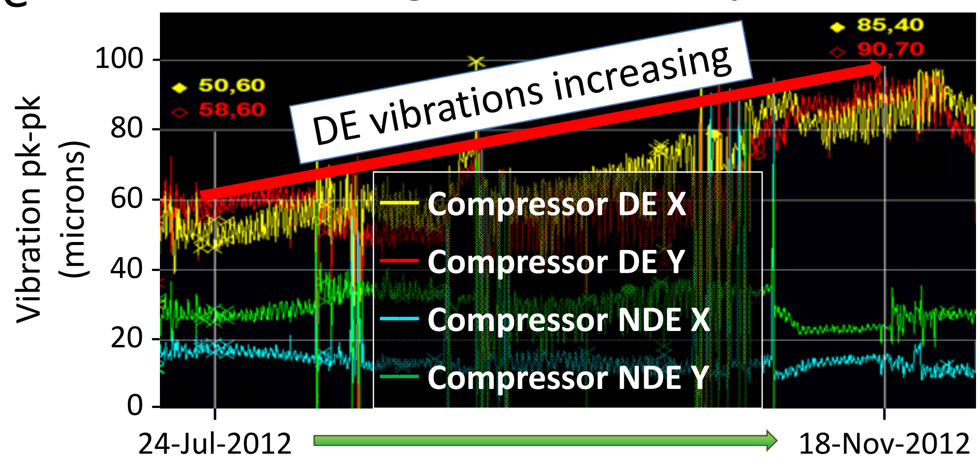
Unit Background Information

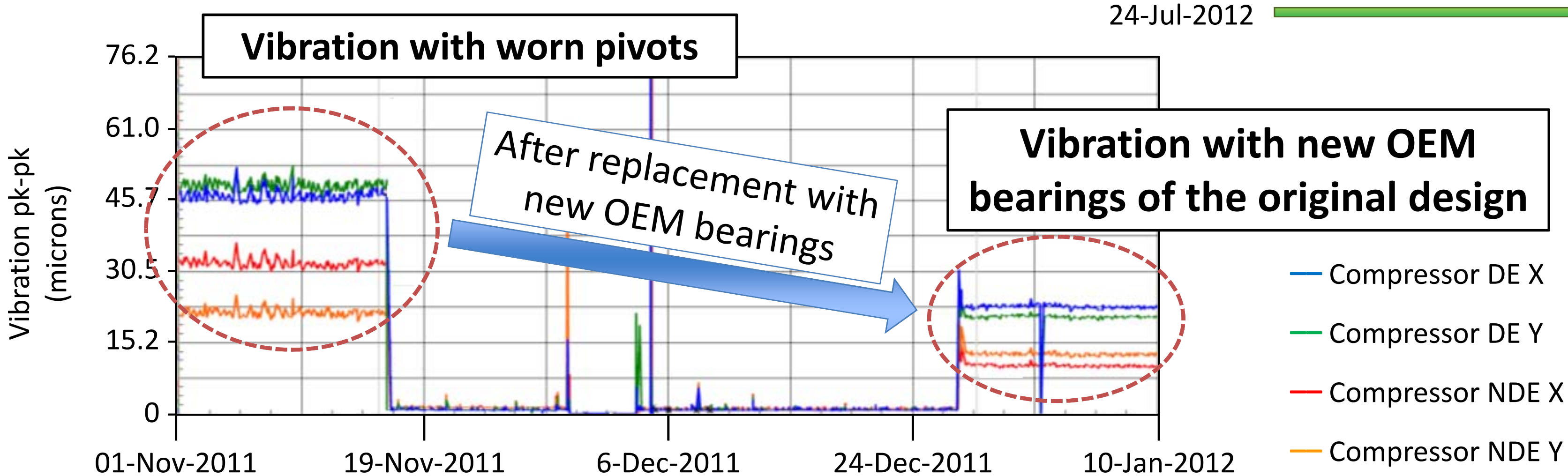
- 3 gas reinjection compressor trains operating since 2000
- Each compressor train has two casings
  - First casing (LP) experienced vibration issues
  - Second casing (HP) did not have vibration issues
- Discharge pressure: 33 MPa
- Rated speed: 11,456 rpm
- OEM bearing information
  - 114.3 mm bore x 50.8 mm long TPJ
  - 5-pad, load on pad
  - 60% offset

Problem Statement

- Rotor vibration levels increased over time
  - Downtime due to high vibrations resulted in about **1% loss in production** time and additional flaring gas
  - **Field balanced every year**
  - Installation of **new OEM bearings every year**

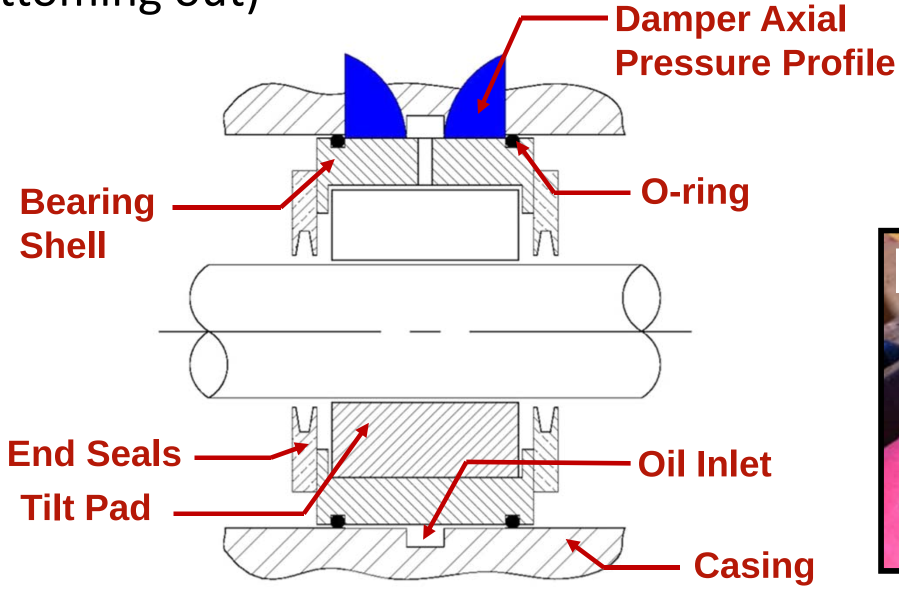
Vibration trend of LP compressor with OEM bearings over 5-month span





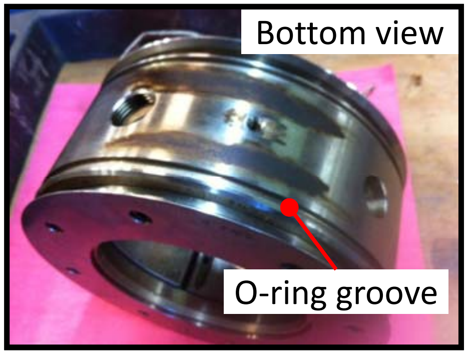
Root Cause

- Severe pivot wear in TPJ bearings
  - Bearing clearance **increased** by **63+** microns
- O-ring damper performance changed
  - Damper film **eccentricity ratio change** (bottoming out)

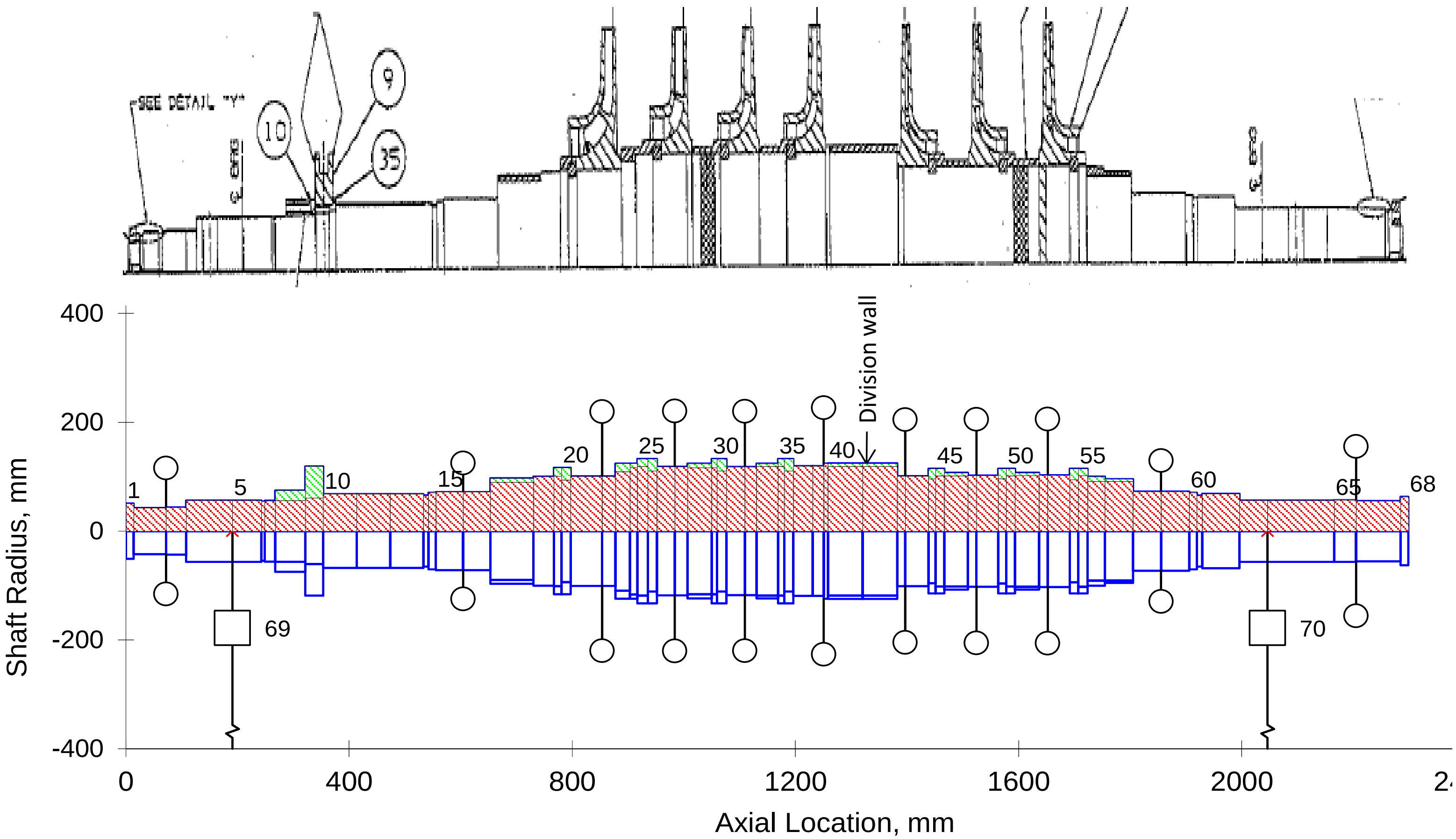


Pivot wear

Fretting damage on bearing OD

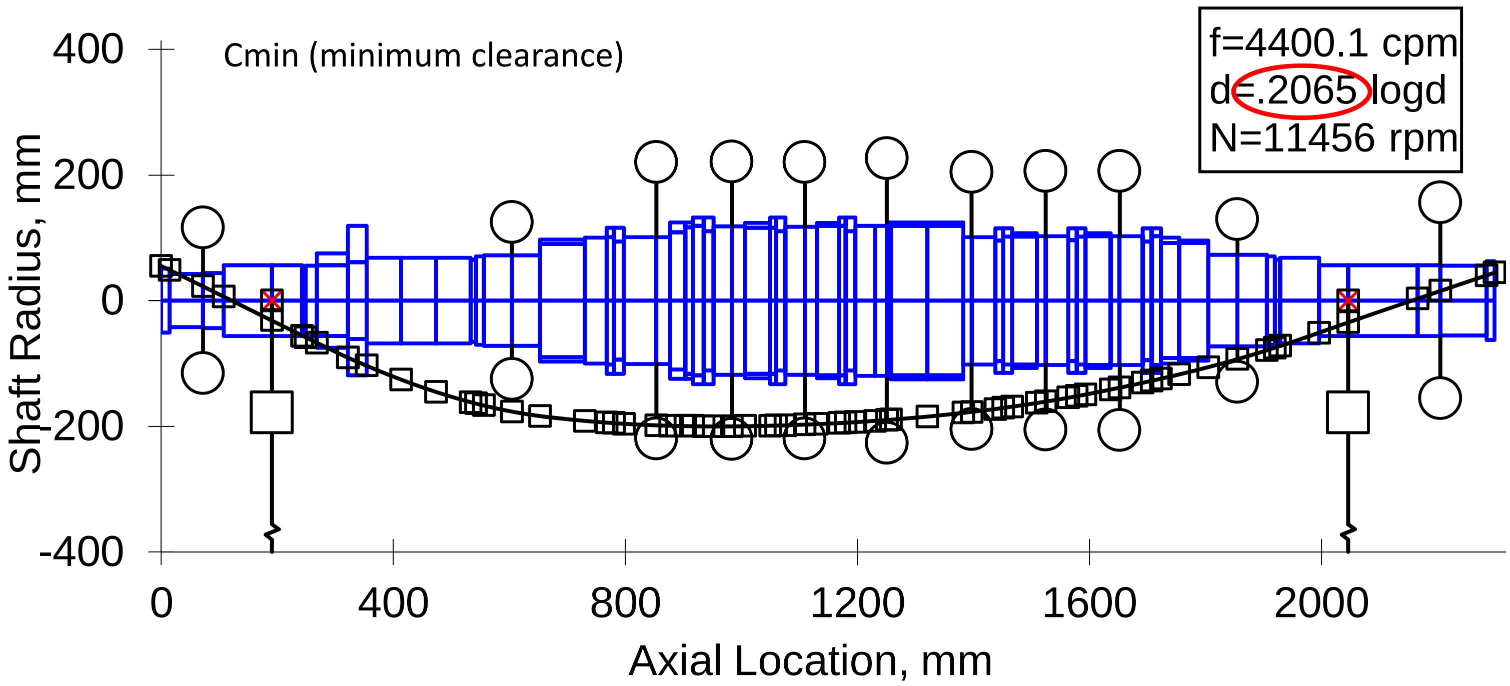


Rotordynamic Model



Baseline Mode Shapes with OEM Bearings

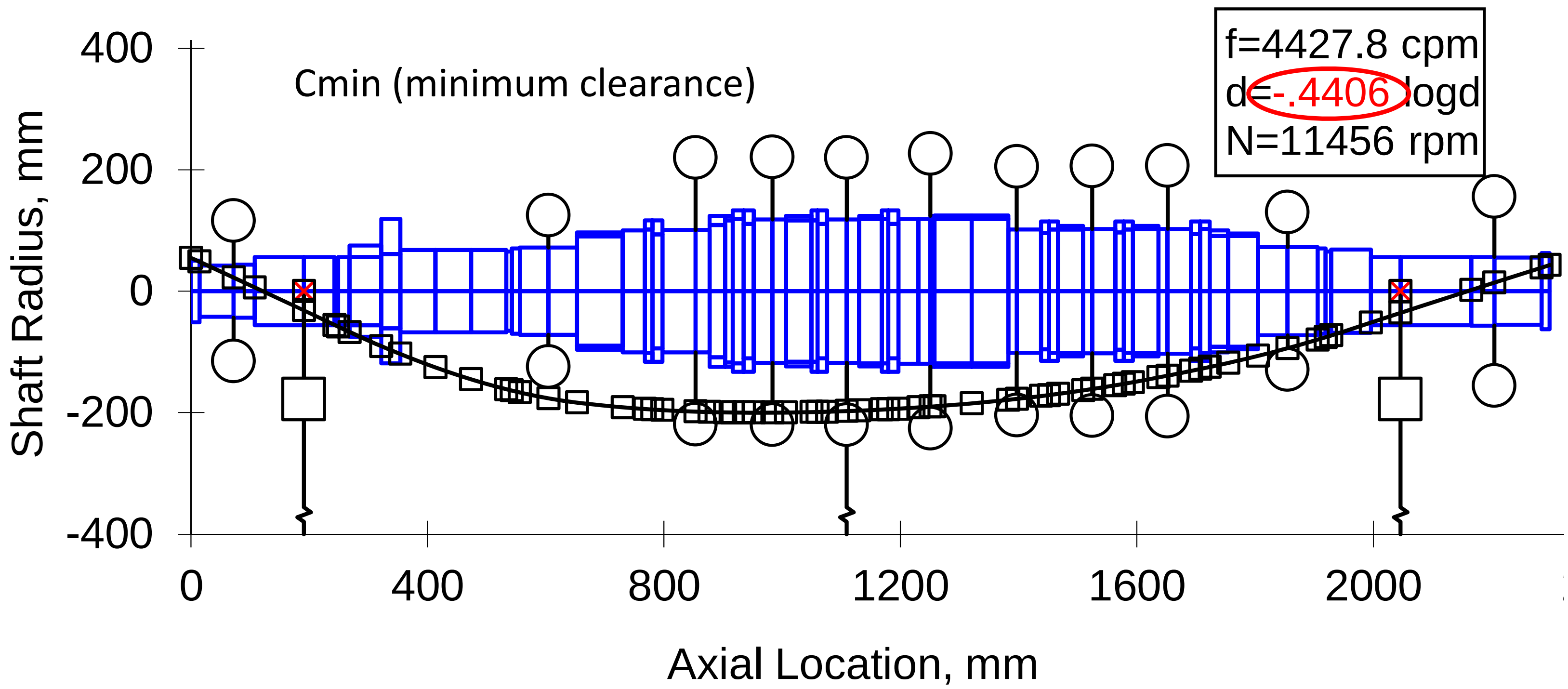
- **Small log dec** for baseline model (no SFD and no aero cross-coupling stiffness from seals and impellers)



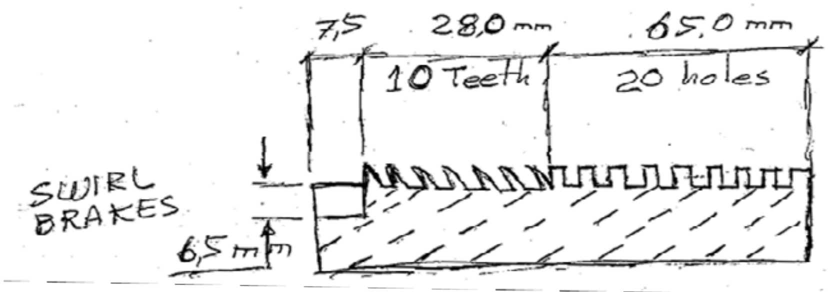
Stability with OEM Bearings

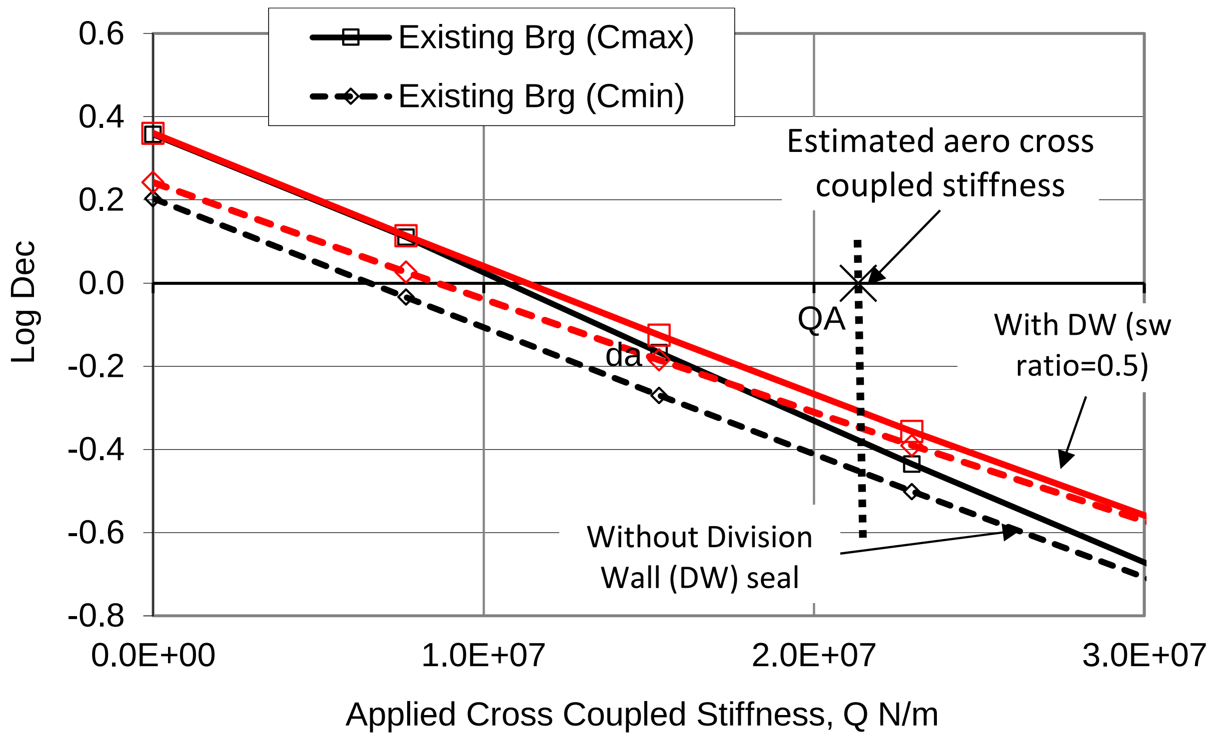
- Level I stability predicts that the rotor is unstable without SFD

$$Q_A = \frac{(HP)B_cC}{D_cH_cN}\left(\frac{\rho_d}{\rho_s}\right) = \frac{(15000)\cdot(3)\cdot(63)}{(19.64)\cdot(0.78)\cdot(12142)}\cdot(8) = 121.932\,\frac{klb}{in}\,or\ 2.13E07\ N/m$$



Division Wall Seal Contribution





- Insignificant improvement to stability with division wall **hole pattern seal**
- For stability, **SFD** required

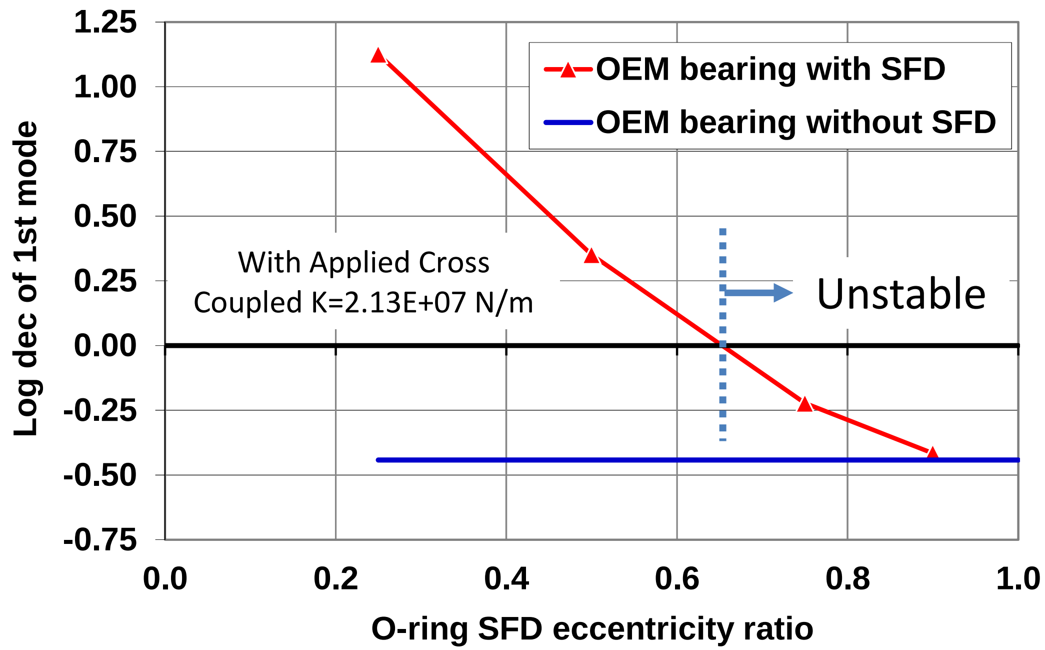
O-ring Squeeze Film Damper (SFD)

- Damper radial clearance (c) = 0.110 mm
- Damper radius (R) = 95.25 mm
- Effective damper length (L) = 37.85 mm
- Stability is very sensitive to damper eccentricity ratio (ε)
- Added O-ring stiffness

$$K = \frac{2\mu R L^3 \varepsilon\omega}{c^3(1-\varepsilon^2)^2} \qquad C = \frac{\pi\mu R L^3}{c^3(1-\varepsilon^2)^{3/2}}$$

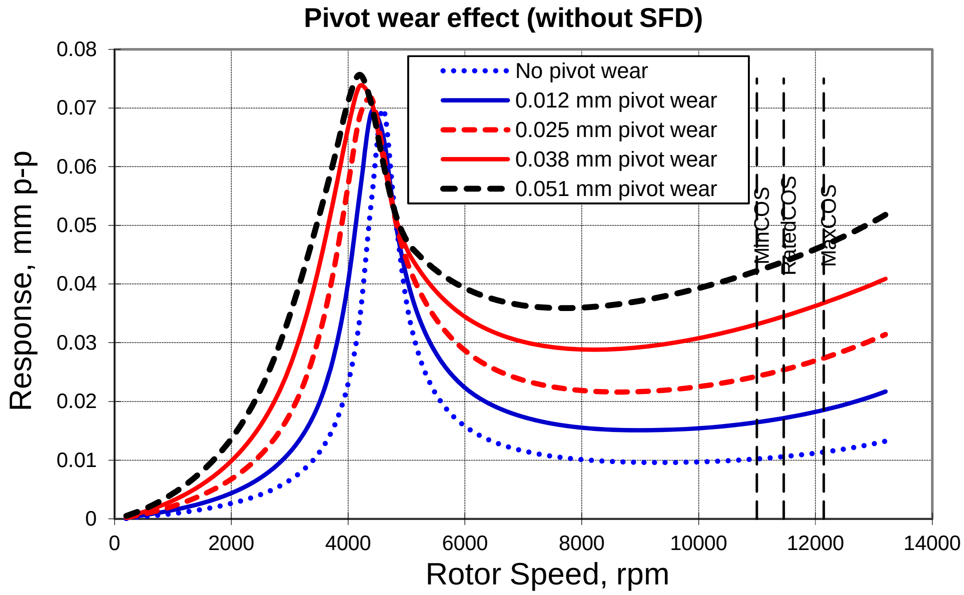
Damper stiffness and damping coefficients (without O-ring stiffness):

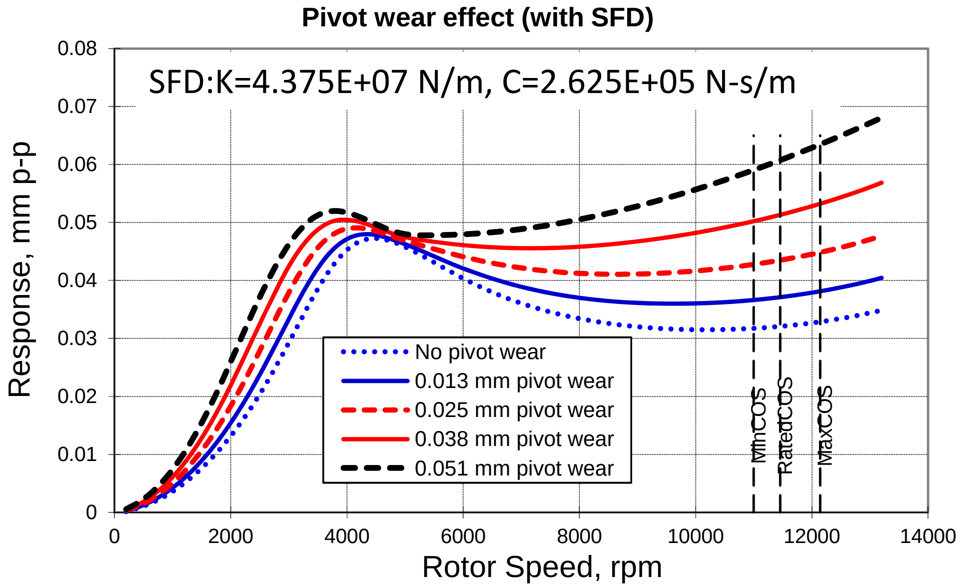
K=1.94E+07 N/m, C=1.88E+05 Ns/m at ε=0.25
K=6.06E+07 N/m, C=2.62E+05 Ns/m at ε=0.50
K=1.70E+09 N/m, C=2.06E+06 Ns/m at ε=0.90



Pivot Wear Effects on Synchronous Vibration

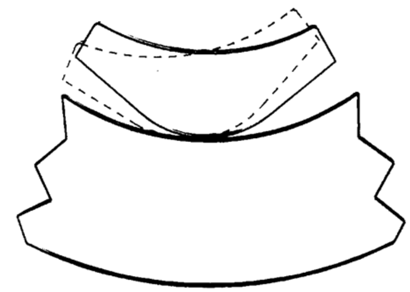
- Pivot wear increased operating bearing clearance and reduced preload, resulting in increased synchronous vibrations
- A bearing with an SFD can make the rotor less sensitive to pivot wear than a bearing without an SFD



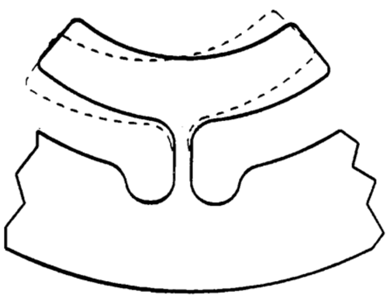


Bearing Upgrades (Journal Bearing)

1. Flexure Pivot Tilt Pad Journal Bearing
   - **No pivot wear**
     - Integral pivot
     - Maintains bearing clearance
   - High pivot stiffness
     - No pivot stiffness effect on bearing dynamic coefficients
   - Tight control of clearance and preload
     - Electrical Discharge Machining (EDM)
   - No pad flutter



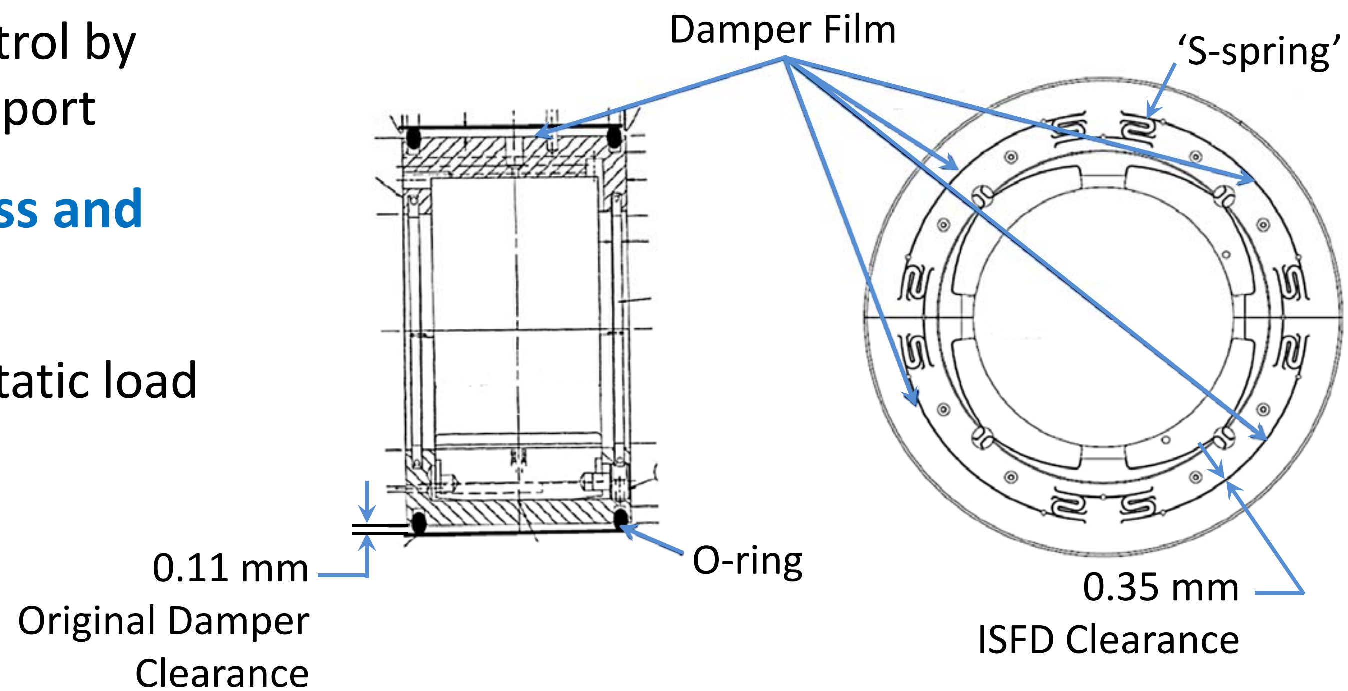
Conventional Tilt Pad Journal Bearing (Rocker Back)



Flexure Pivot Tilt Pad Journal Bearing

Bearing Upgrades (Damper)

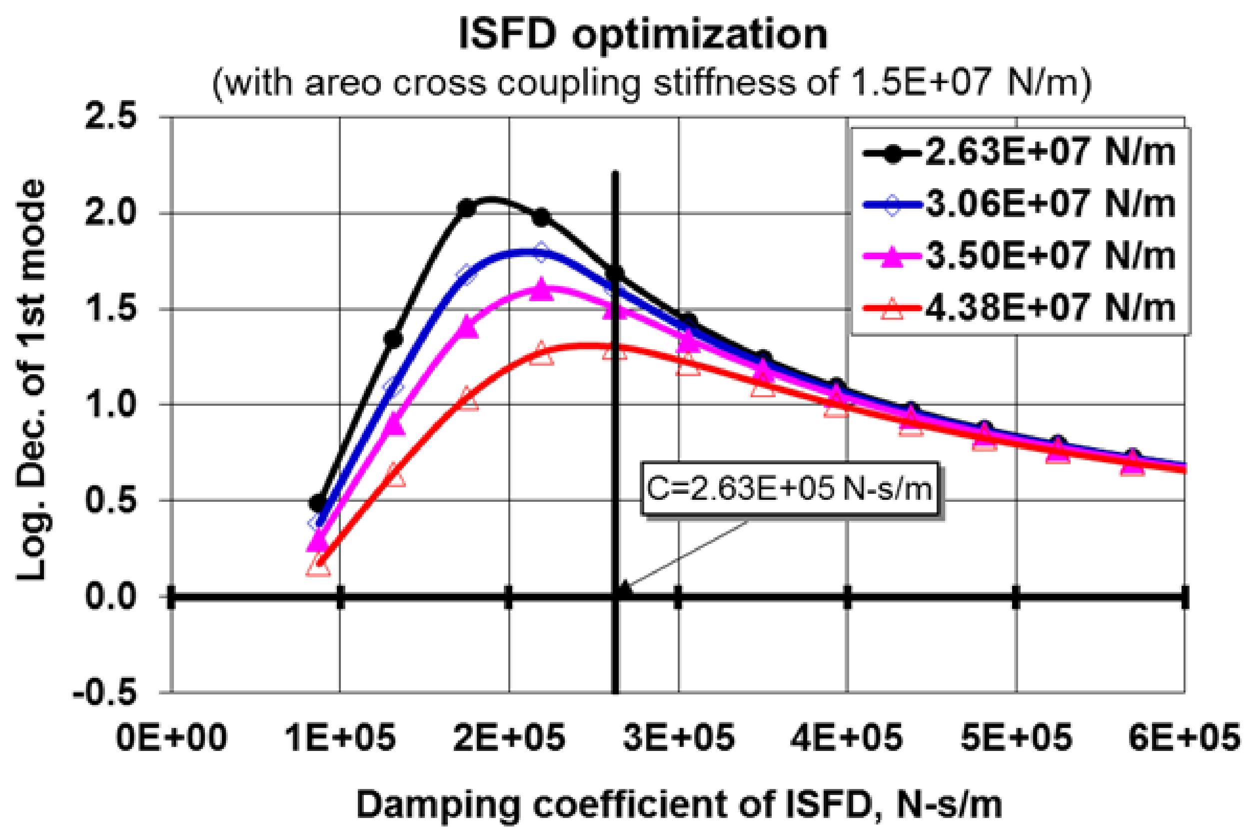
2. Integral Squeeze Film Damper (ISFD)
   - Accurate stiffness control by eliminating O-ring support
   - **No change in stiffness and damping over time**
   - Designed to counter static load
   - Optimized damping
   - Less cavitation



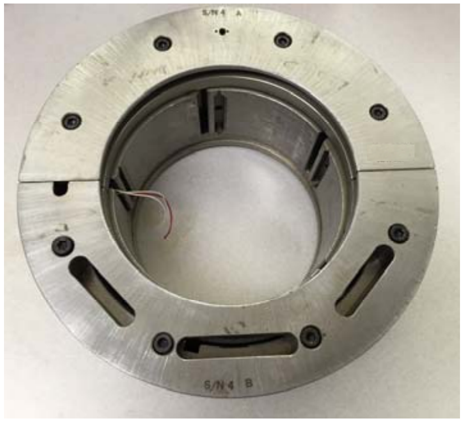
Conventional SFD **ISFD**

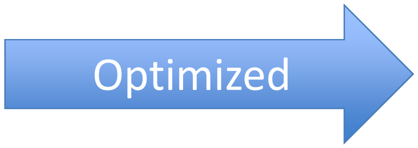
Optimization of ISFD

- Optimized stiffness and damping are 4.375 E+07 N/m (250,000 lb/in) and 2.625E+05 N-s/m (1500 lb-s/in)
- Additionally, the ISFD is designed to center the Flexure Pivot TPJ under gravity load by countering the static deflection



Redesigned Bearing

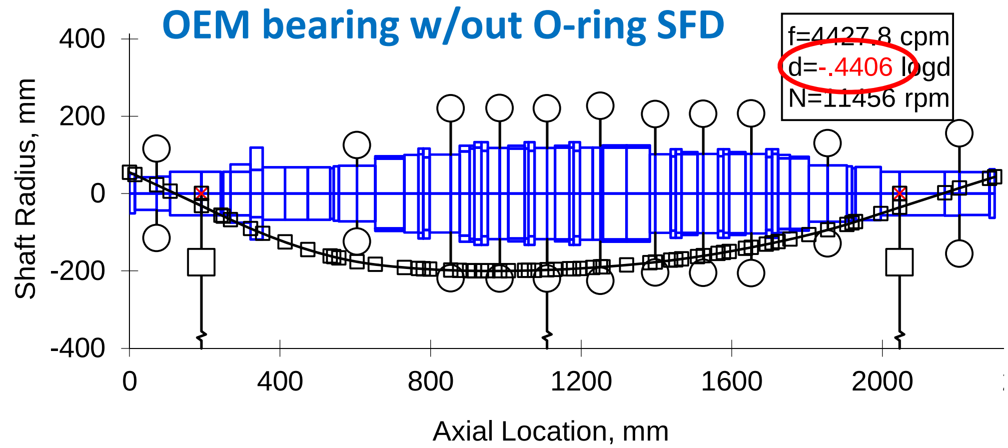


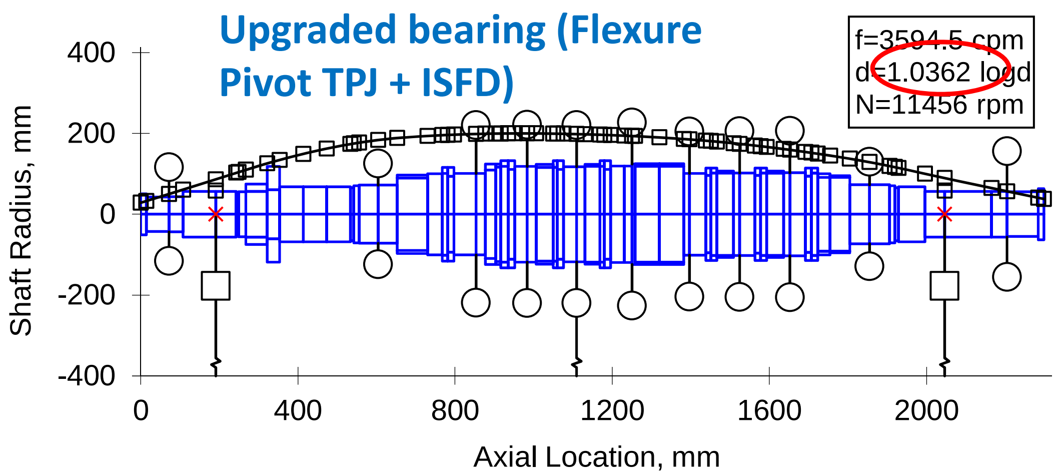


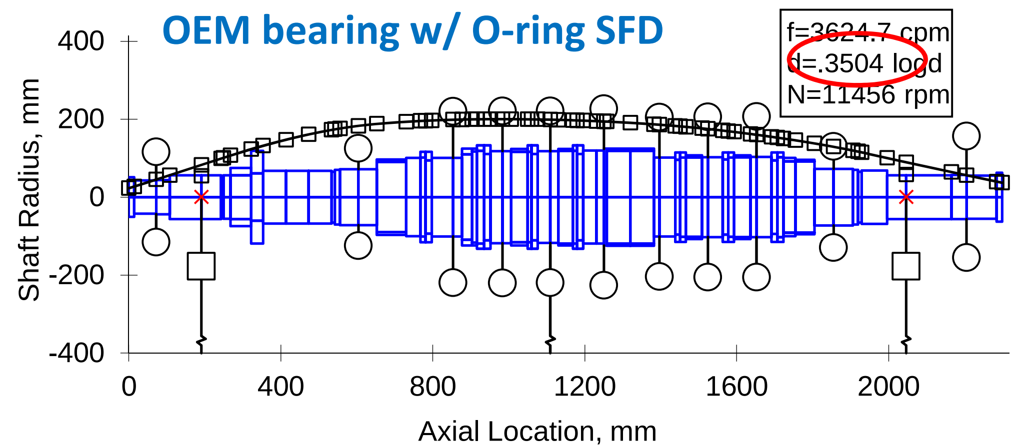
Original Design			Optimized Design		
Conventional TPJ with SFD			Flexure Pivot TPJ with ISFD Technology		
5-pad, Load On Pad			4-pad, Load Between Pad		
Shaft diameter	114.300 +0/-0.013	mm	Shaft diameter	114.300 +0/-0.013	mm
Bearing bore	114.414 +0.025/-0	mm	Bearing bore	114.427 +0.025/-0	mm
Clearance range	0.124/0.156	mm	Clearance range	0.124/0.156	mm
Preload range	0.293/0.501		Preload range	0.230/0.273	
L/D	0.444		L/D	0.500	
Pad arc	60°		Pad arc	72°	
Pivot Offset	60%		Pivot offset	55%	

1^{st} Mode Shapes: Original and Upgraded Bearings

- Applied destabilizing cross-coupling stiffness of 2.13E+07 N/m to mid-span
- Without SFD, unstable
- Both O-ring SFD and ISFD can make the rotor stable
- No change in stiffness and damping of ISFD over time



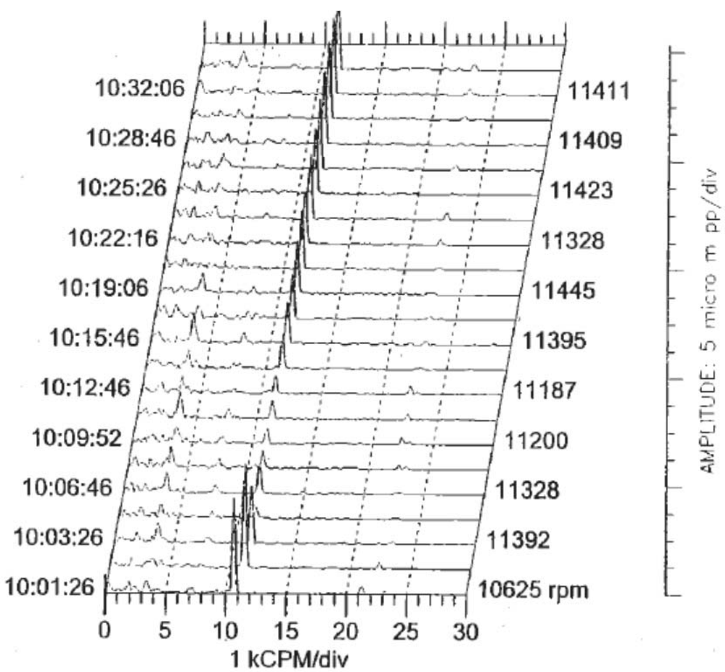




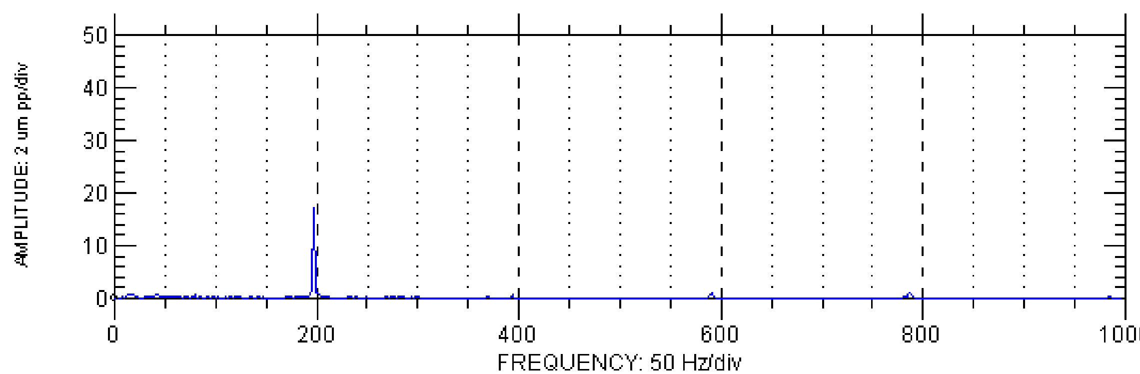
No Subsynchronous Vibration (SSV) with Upgrade

- Small SSV with O-ring SFD
- No SSV with ISFD

With OEM bearing (Acceptance test)

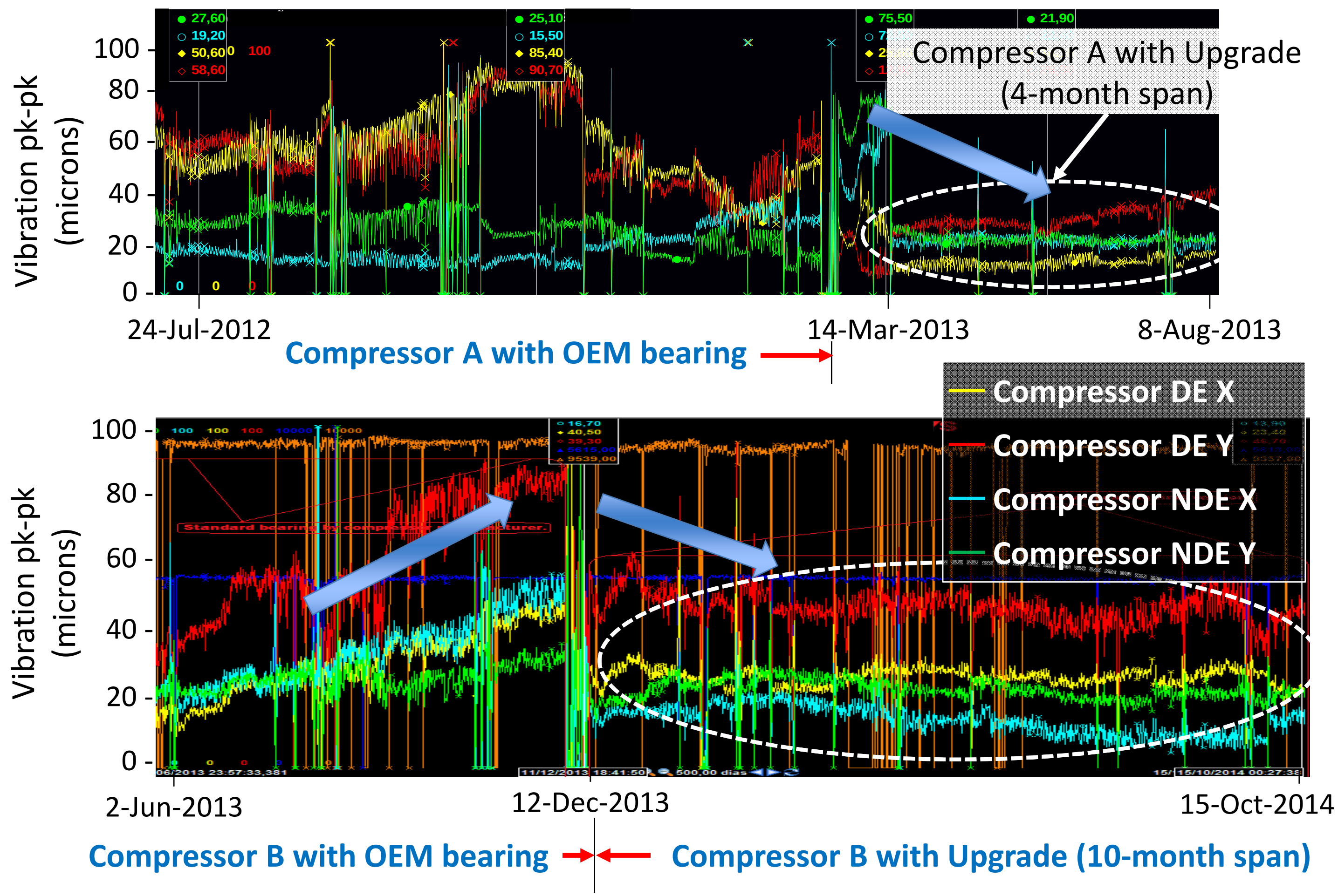


Upgrade bearing



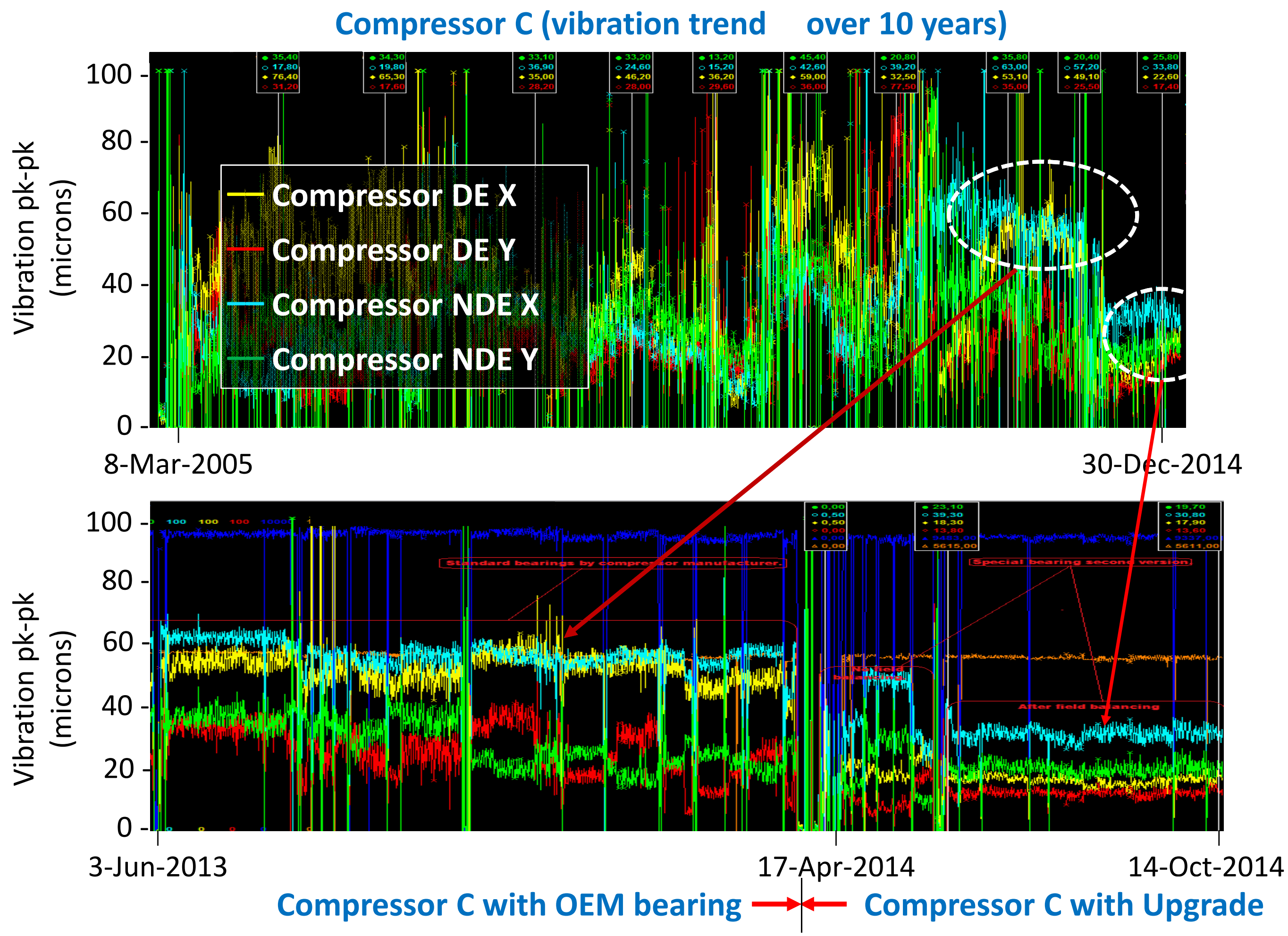
Vibration Improvement (Comp A & B)

- Compressor A vibration dropped to **less than half** and maintained that level over time
- Compressor B vibration also down to **below 50 µm** from 90 µm (original) and kept the same level over time



Vibration Improvement (Comp C)

- Compressor C was also upgraded with a Flexure Pivot TPJ with ISFD technology
- Again, the vibration level decreased to **below 30 µm** with the upgrade and maintained that same level due to no change in bearing clearance and SFD performance over time



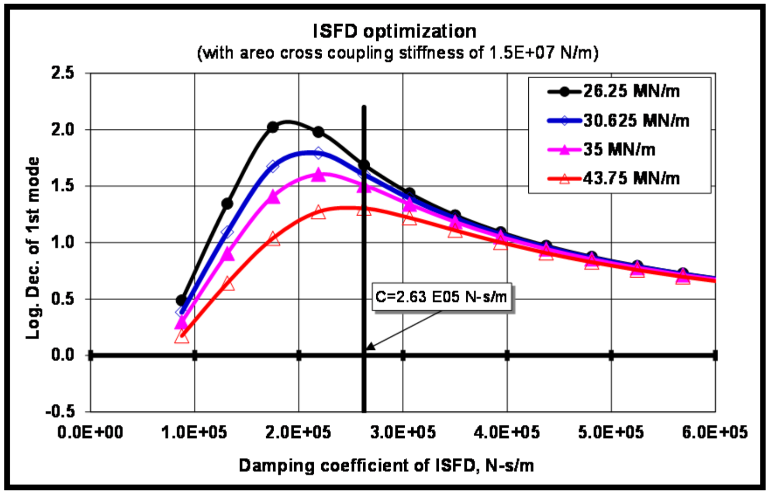
Summary

- Three reinjection compressor trains suffered from **excessive vibration** over many years
  - Original configuration: point contact pivot tilt pad journal bearings with an O-ring SFD
- The root cause was **excessive pivot wear** and **degradation** of the **O-ring SFD**
  - Bearing bore increased
  - Stiffness and damping changed over time

Summary

- The compressors were retrofitted with optimized **Flexure Pivot** tilt pad journal bearings with **ISFD technology**

- Operating exceptionally well
  - Since 2013
  - **Low vibration levels**
    - 50% drop pk-pk compared to OEM bearings
    - Do not grow over time
  - **No field balancing required** so far (2 years)
  - **No trips** (continuous production)
  - **No expensive bearing replacements**
  - Overall **efficiency increased** by **1%**



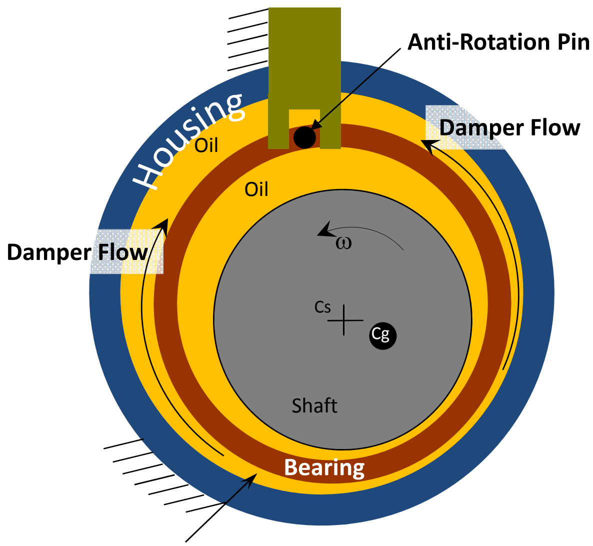
Lessons Learned

- Increase in synchronous vibrations may be an indication of bearing **clearance increasing from pivot wear** and/or **change in O-ring damper performance**
- Pivot wear may accelerate over time from increasing imbalance due to **deposits on impellers**
- Without eliminating pivot wear, just **replacing the worn bearing** with new build of the same design is **NOT a long-term solution**
- **Proper bearing and damper selection and optimization** can reduce or eliminate the likelihood of increasing vibrations and pivot wear
- **Flexure Pivot technology** is a proven design to eliminate pivot wear
- **ISFD technology** maintains performance over time

Feedback and Questions

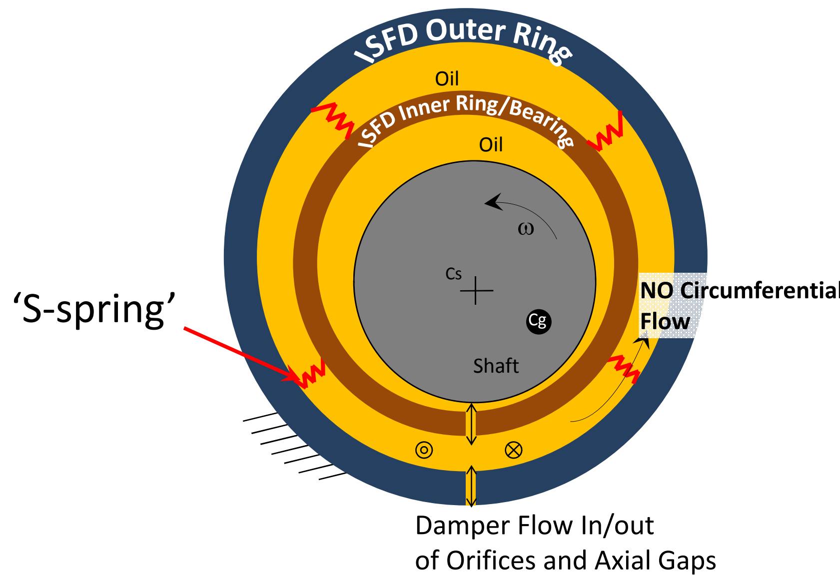
Case Study: A Solution to Years of High Vibration Problems in Three Reinjection Compressor Trains Running at 33 MPa Discharge Pressure

Appendix: Damper Design Comparison



Squeeze Film (Outer Oil Film) – bearing whirls or orbits (not spins) in a precessional motion due to synchronous (unbalance) or non-synchronous excitation, squeezing the oil and thus generating an oil film pressure, and subsequently a damping force. Flow can be axial too, depending on sealing.

Conventional SFD



Integral Squeeze Film Damper

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