Reliability improvements on high speed reciprocating compressors through bearing and process modifications

- Case Study

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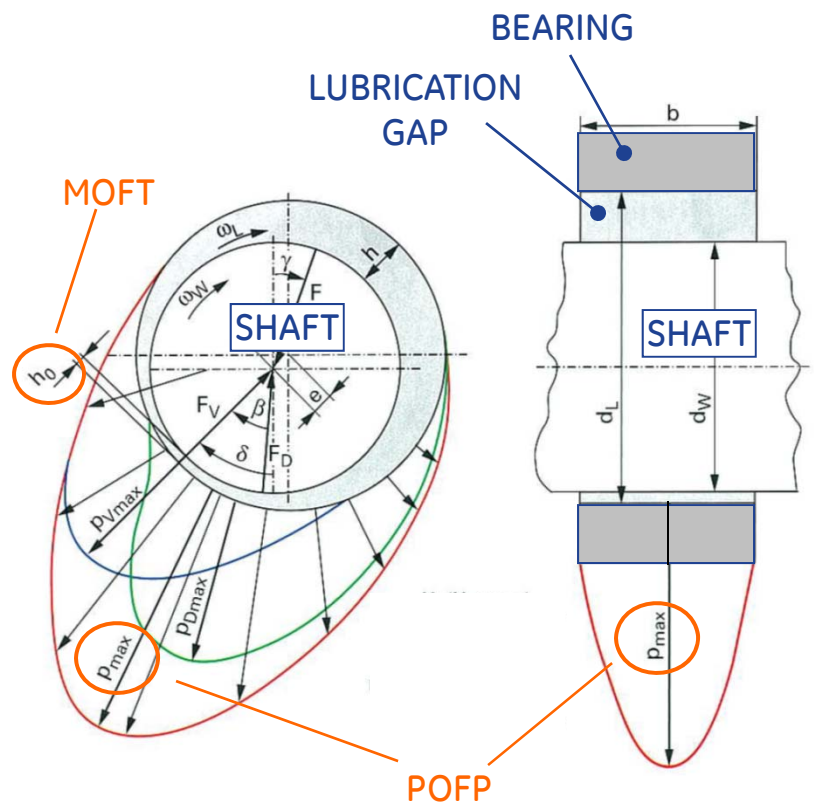
Contents

Bearing analysis - Background

Fluid friction needed to minimize power losses and rapid wear → *Hydrodynamic operation*

Bearing operating principle

- The reciprocating motion of the shaft generates a variable lubrication film thickness: the pin changes its position both circumferentially and radially
- The geometry of the bearing gives a pressure trend within its width

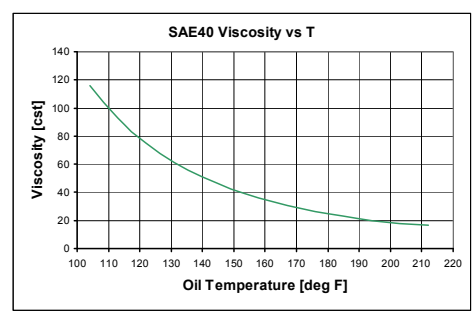


Bearing performance

- To avoid rapid bearing wear:
  - Adequate separation between moving components (↑ MOFT)
  - Low stress level (↓ POFP)

Bearing design criteria

- Wide bearing surface to ↓ POFP
- ↓ oil inlet T and ↑ cooling flux to ↑ oil viscosity and therefore ↑ MOFT



RCA Process – Key Parameters

Bearings

- overloaded Babbitt
- geometry out of cylinder/ parallel
- improper clearance
- oil delivery improper (flow/ temp)
- contaminated lubricant
- anti-rotation tab deform
- surface hardness mismatch
- debris imbedded
- poor fit / contact pressure

Crankshaft

- overloaded journal
- geometry out of cylinder/ parallel
- oil delivery improper to bearing

Conn Rod

- uneven /improper bearing housing
- geometry out of tolerance/ assy fit
- oil removal uneven or improper

Lubrication System

- Packager– oil delivery (temp/ press variation)

Approach

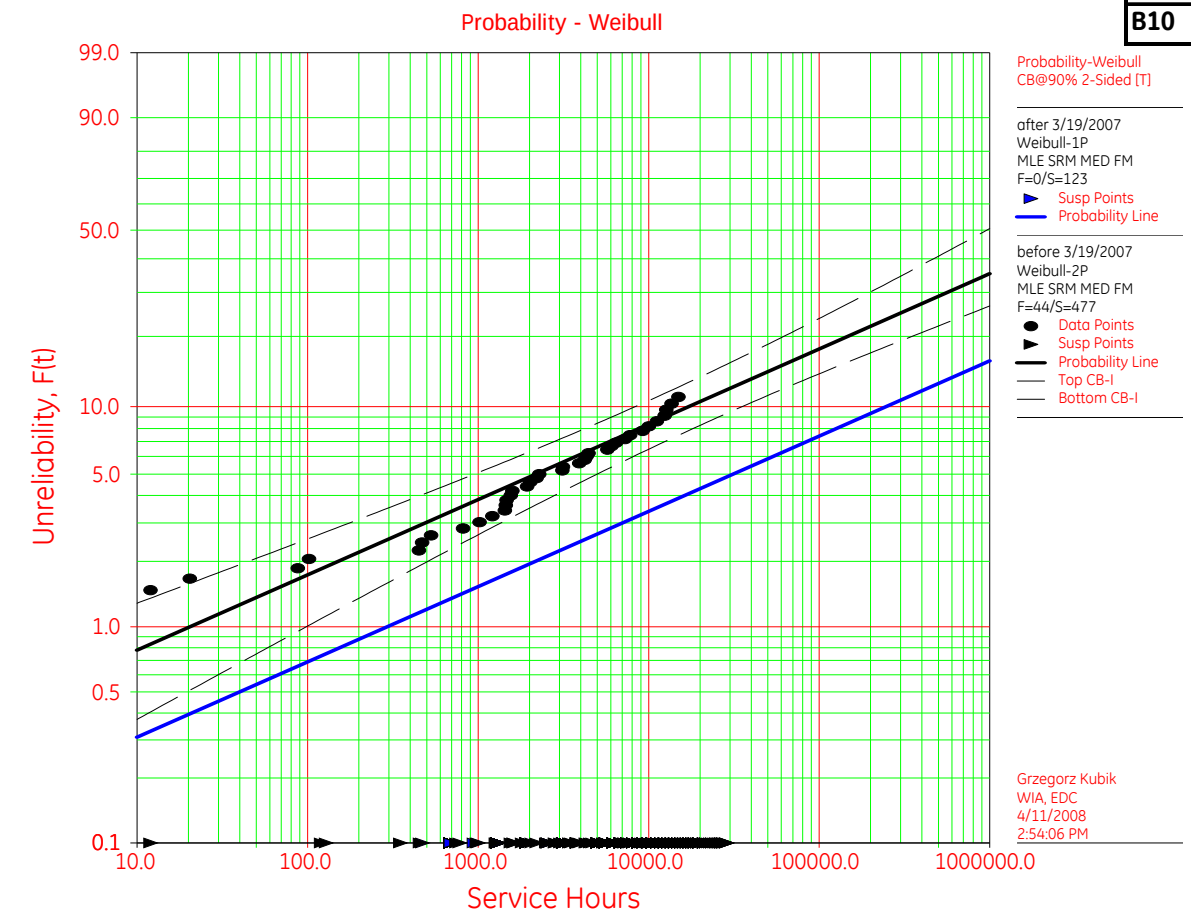
The first major focus of this effort was to **eliminate the early operation (infant mortality) issues** by addressing the fundamental part/ unit quality issues.

- An extensive effort was made to work with the crankshaft, connecting rod, and bearing manufacturers to ensure the **critical to quality component features** were maintained (CS pin cylindricity, CS pin surface finish, bearing as-assembled roundness, tin-flashing consistency, etc.).
- The compressor team also focused on cleanliness **processes and in-house inspections** for increased confidence as well.
- At the same time, the high speed recip OEM had extensive P&ID reviewers with the **packagers and were able to get lube oil supply temperatures** and pressures to be delivered in a much more consistent way.

Within a late 2006 to early 2009 period, the two-year operational reliability increased from ~90% to 100% (that is, no new bearing failure for over 3 years of shipments now).

Bearing Weibull Analysis

	Before 3/19/2007	After 3/19/2007
No of Failures	44	0
No of Suspensions	477	123
Beta	**0.35**	**0.35**
Eta	**10,874,385**	**156,206,865**
MTTF	55,268,030	794,239,601
B10	17,202	246,915



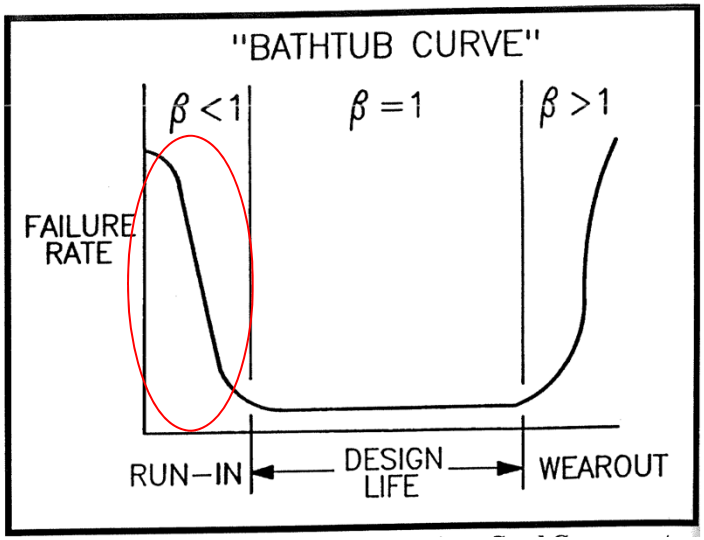
after 3/19/2007: β=0.3489, η=1.5621E+8
before 3/19/2007: β=0.3489, η=1.0874E+7

- Weibull analysis shows $\beta = 0.35$.
- This indicates an Infant Mortality failure mechanism.
- The units produced since Mar-2007 demonstrate 14 times improvement in Reliability

Weibull Interpretation

	Beta	B10* Life (hrs)
Before improved Cleanliness	.35	17,638
After improved cleaning	.38	26,683
After New Bearing fit/ tab	.27	141,168
After New Factory Inspection	.37	1,691,771

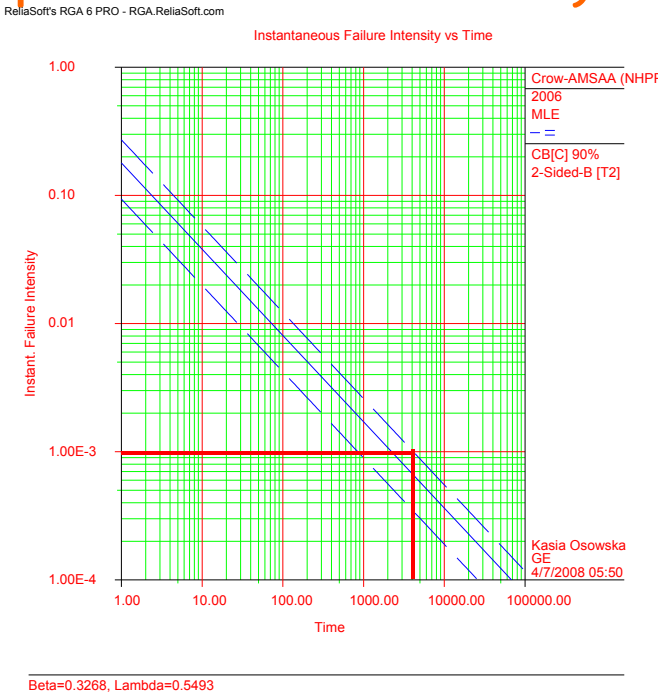
*B10 is the prediction of non-failure of this mode for 90% or more



B10 says 'design life' fall-out is very low; Beta supports failure occurs early in life

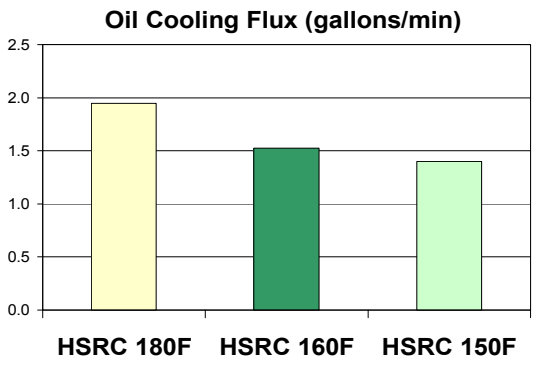
So what about beyond infancy?

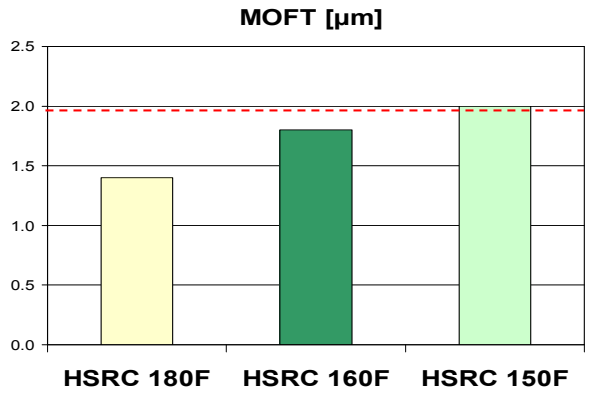
Detail: Crow AMSAA for 2006-ship Units...
for units operating >5000 hrs,
< 0.1% chance of failure in "design life" period (w/ 90% confidence)

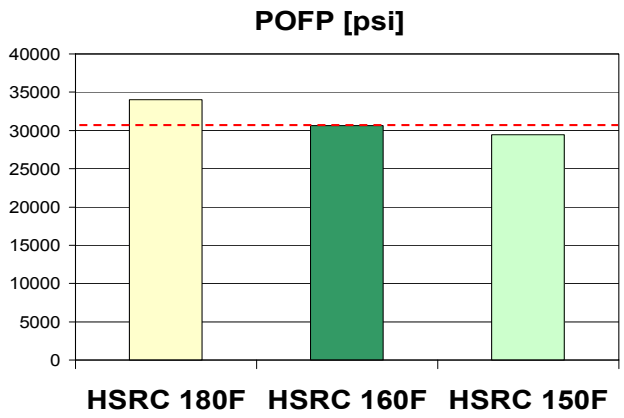


... what else can cause infant failures?

Bearing analysis – HSRC oil cooling effect







= HSRC with actual cooling system (oil temp @ 180F)

= HSRC with upgraded oil cooling system (oil temp @ 160F)

= HSRC with upgraded oil cooling system ("plus" option, oil temp @ 150F)

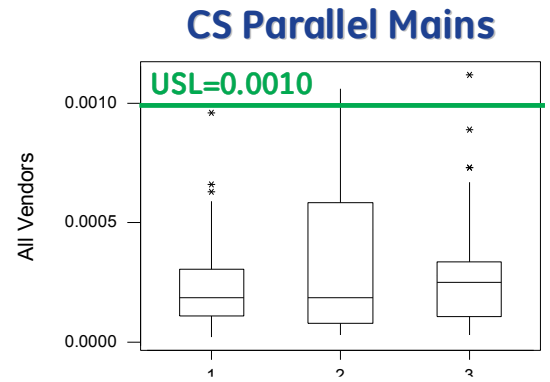
Oil delivery system robustness is key impact to managing good bearing parameters… poor oil control impacts other factors (when MOFT is low)

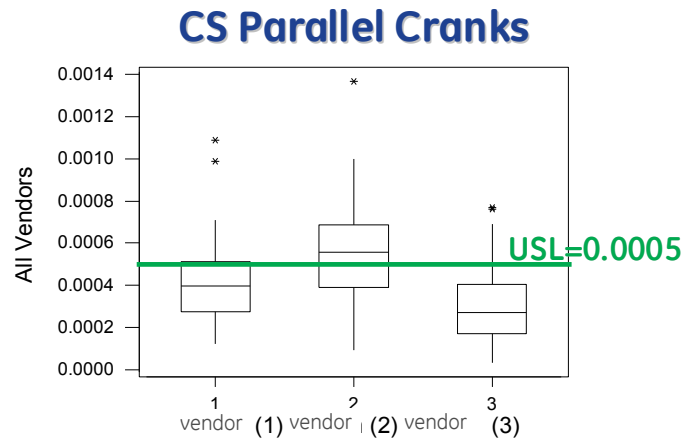
Bearing fit to Journals A Key …

cylindricity/ parallelism

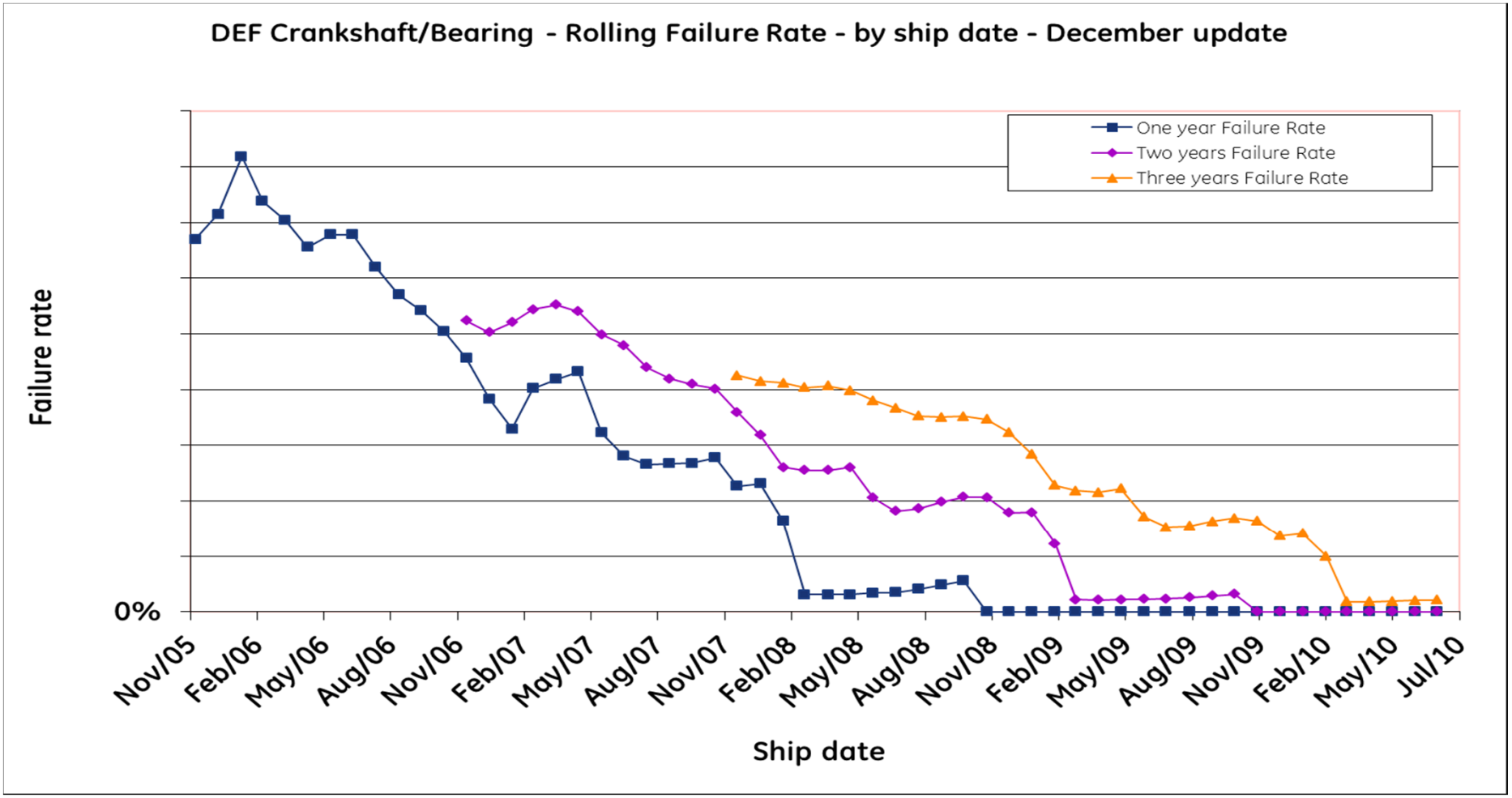
- Crankshaft geometry out of cylinder/ parallel … key manufacturing CTQ with suppliers
  - Main CS journals 'good'
  - Crank journals – vendor variation
    'devil is in the details'

- Also, bearing fit into Conn Rod in the final assembled condition a key to good journal
  - Conn Rod cap torque level and machining are key
  - Bearing 'crush' and deflection key



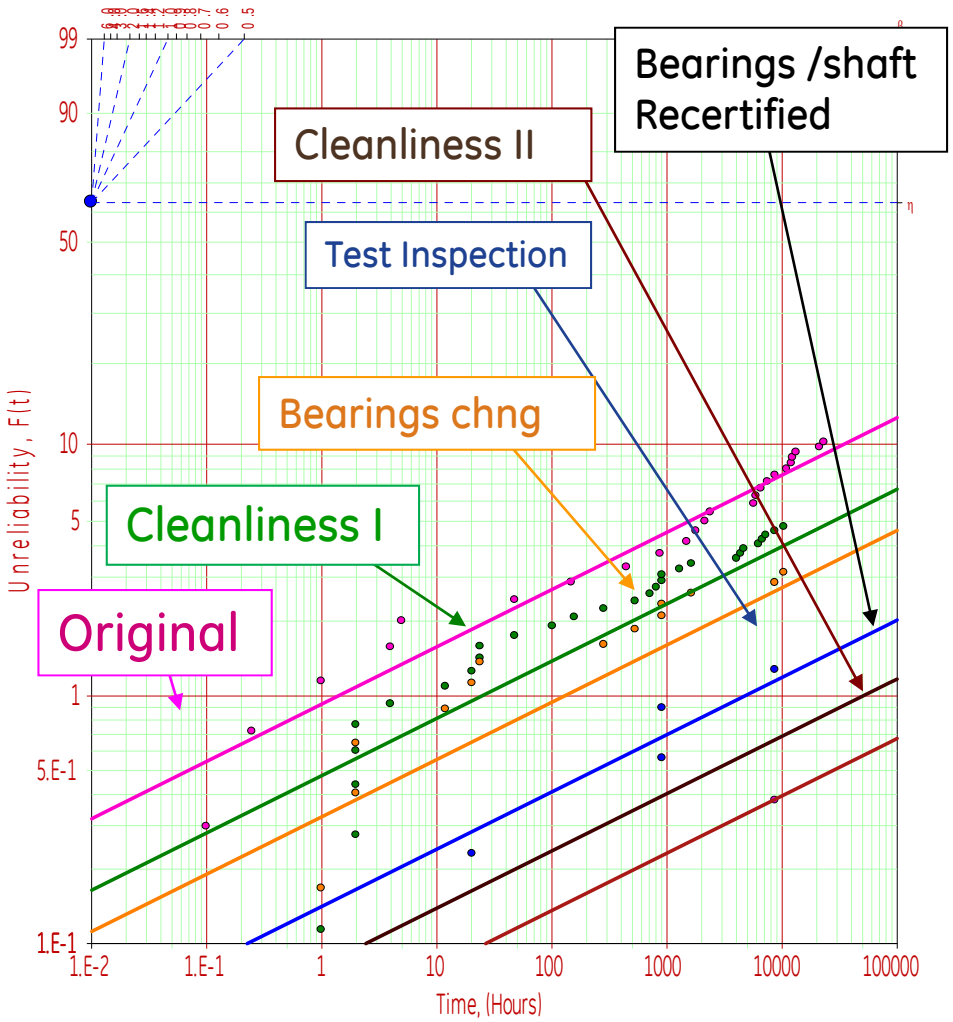


"DEF" Crankshaft/Bearing Rolling Failure Rate

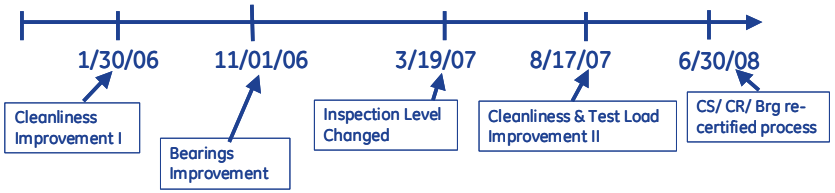


- The last Crank end bearing failure occurred in units produced in Nov 2007.
- **No failures since 3 years of shipment.**

DEF Crankshaft/ Bearing-only Weibull



- Measurable Brg/ CS Reliability step improvement from '05-'08 .... at three years (30 Khrs) : improved from >10% Failure Rate to < 0.5%
- **No bearing failures on units shipped since November 2007...** *although* some customers still limit bearings to ~ 2 years

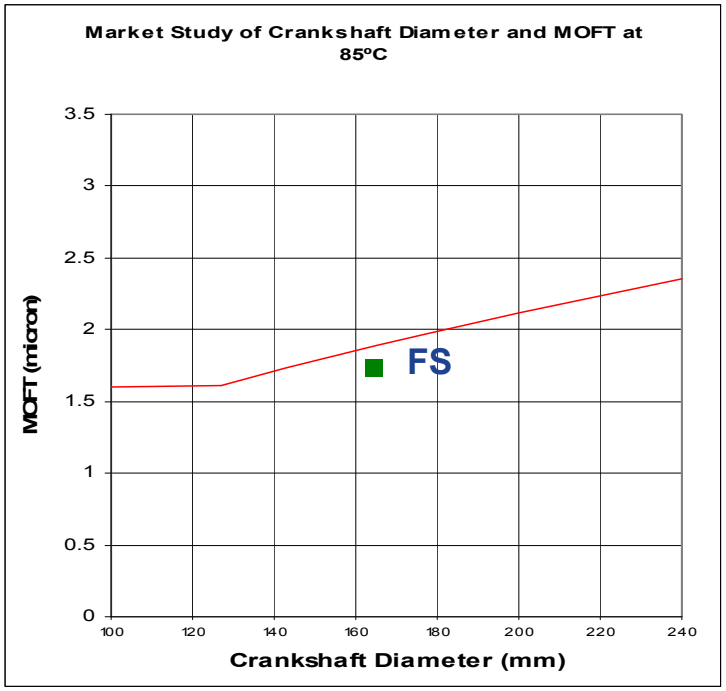


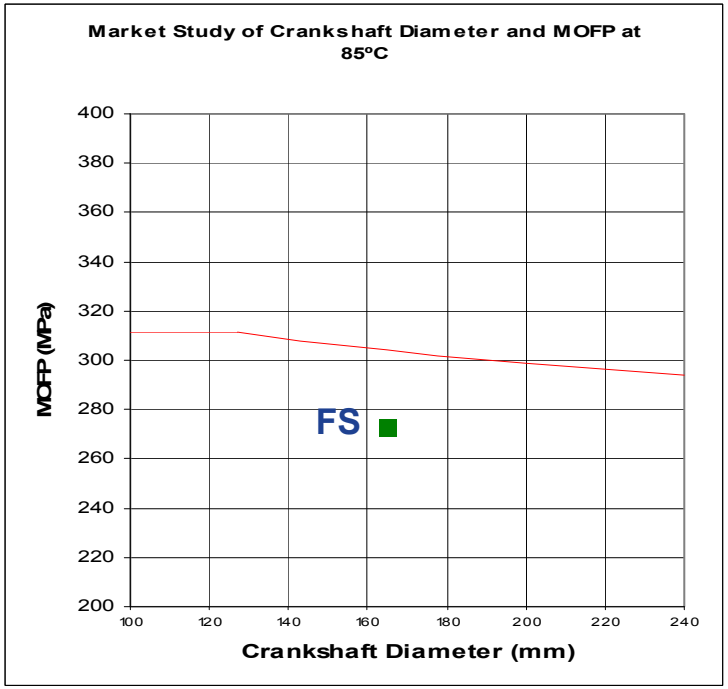
Bearing Design Calculations

Hydrodynamic (HD) calculations have been preformed on a wide variety of compressor connecting rod bearings.

The following general guidelines have been established based on these calculations and actual performance:

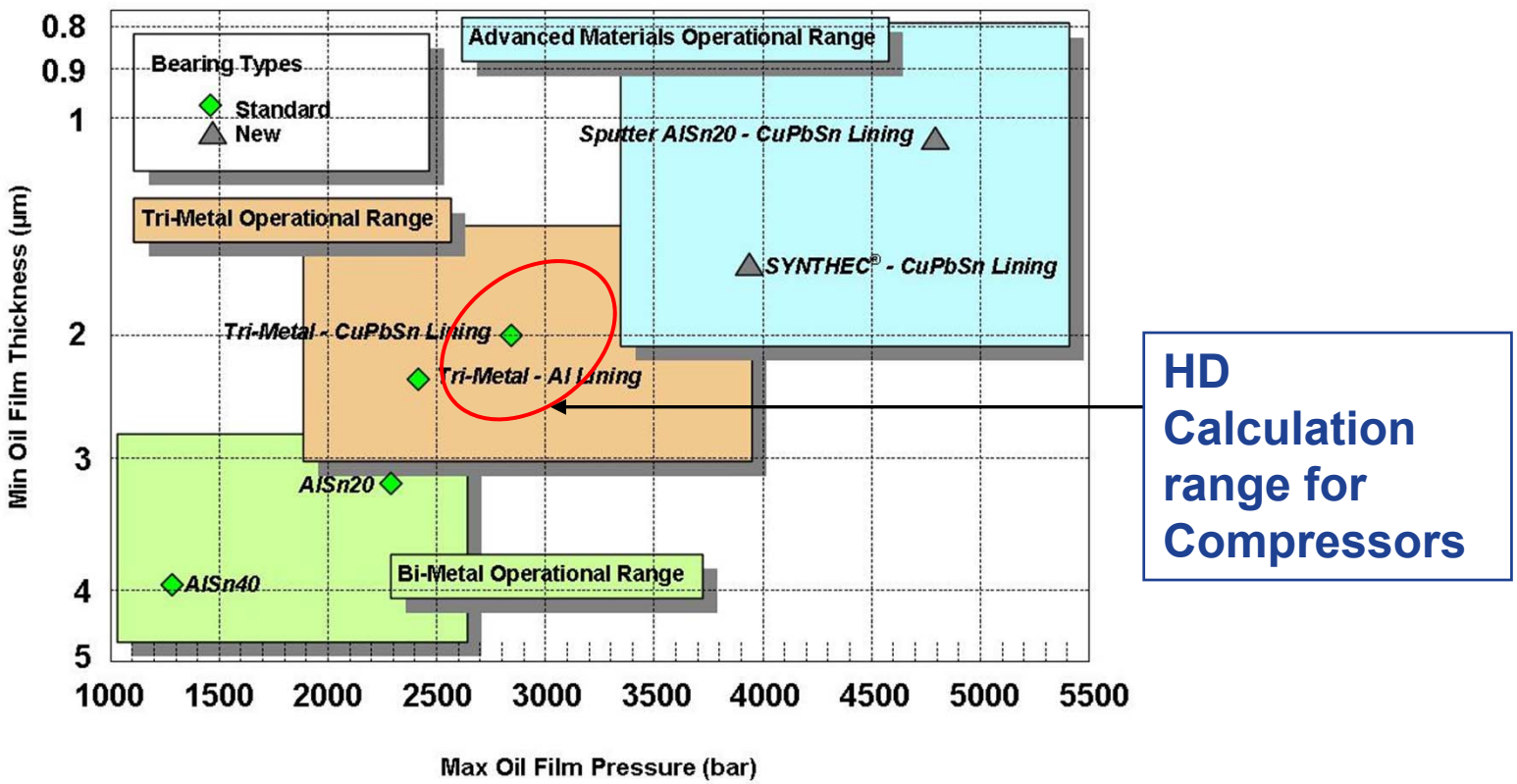
- MOFT greater than 2.0 µm (≈ .00008”)
- MOFP less than 3000 bar (≈ 43000 PSI)



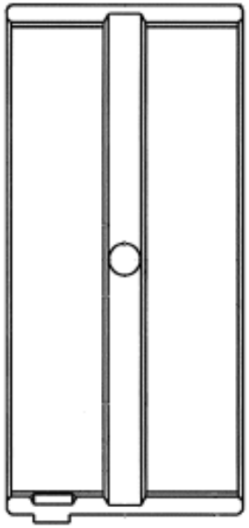


Bearing Materials

- Steel Backed Leaded Bronze Tri-metal bearings are the default material choice for compressor rod bearings. Given that MOFT range from roughly 2.0-3.0 and MOFP averages around 3000 bar on the rod bearings.
- Bi-metal Aluminum lined bearings are sometimes used. However, these are mainly for sour gas (H_2S) applications that will destroy the leaded bronze bearings.
- The main bearings see much less loading than the rods (only about 25-30%).

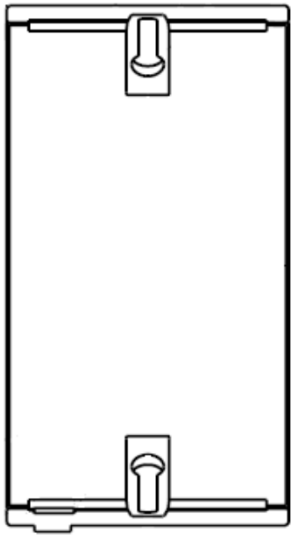


Improved oil feed - NP vs. current style

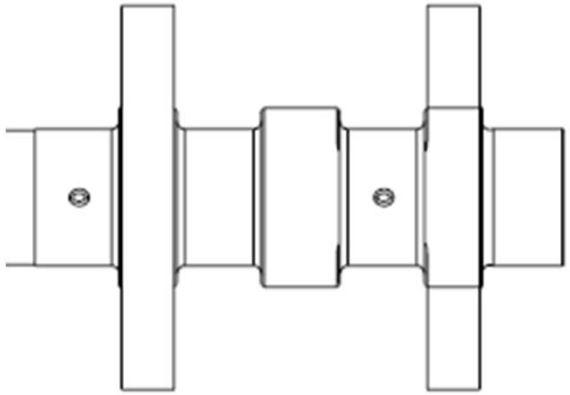


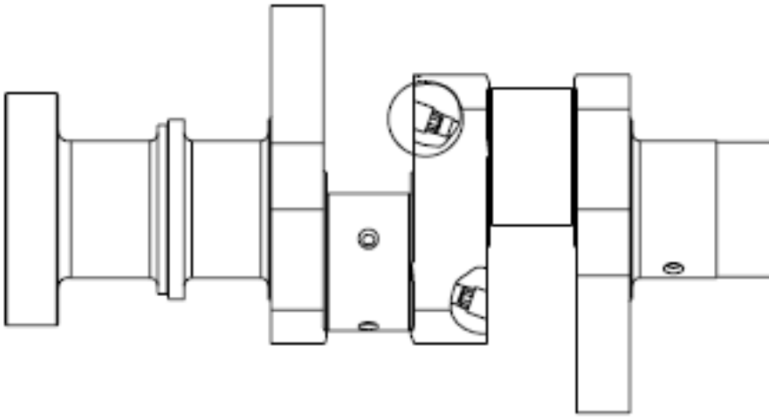
current

- leverages experience from other GE recip products
- Double oil feed / bearing
- Removed circumferential groove at high load
- increased pin width
- improved manufacturing local geometry at crank wall



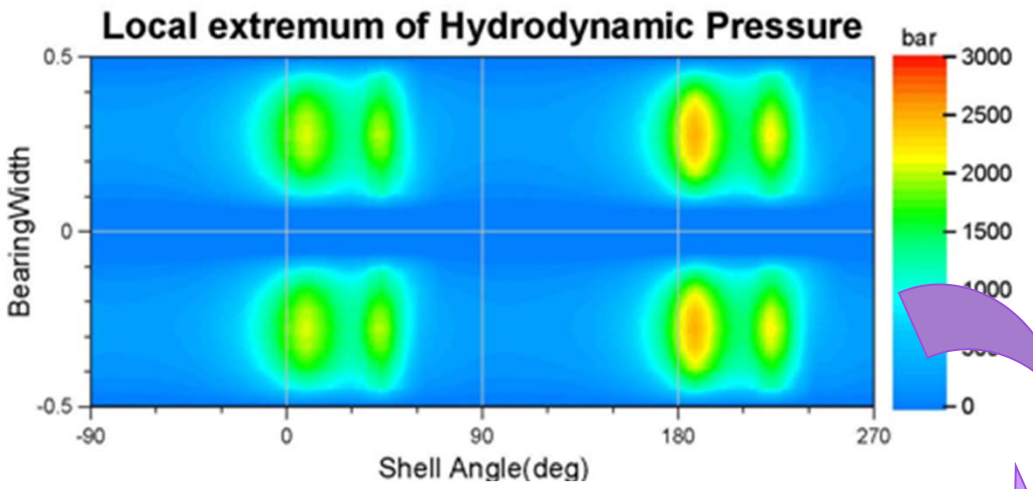
New - NP



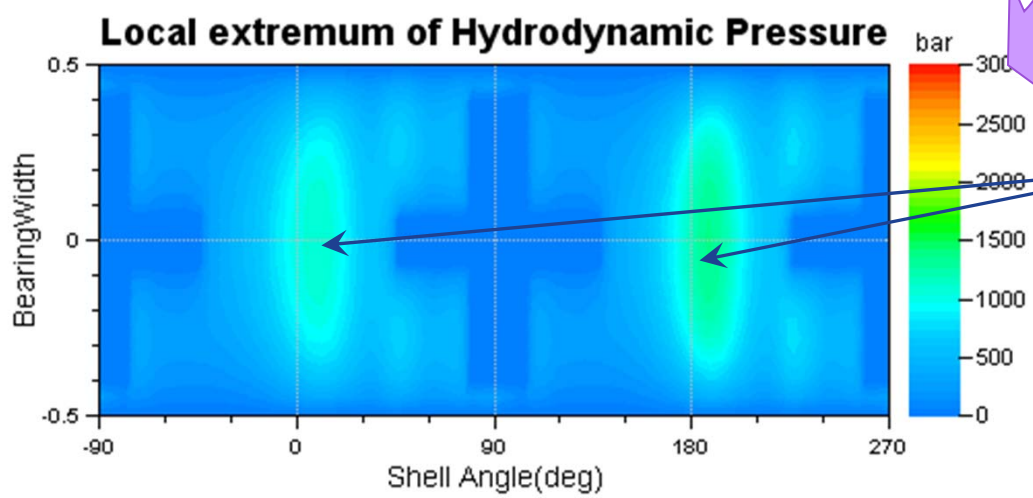


Proposed Changes – NP Style Bearing

Comparison of Standard Bearing vs. NP Style HD Plots.

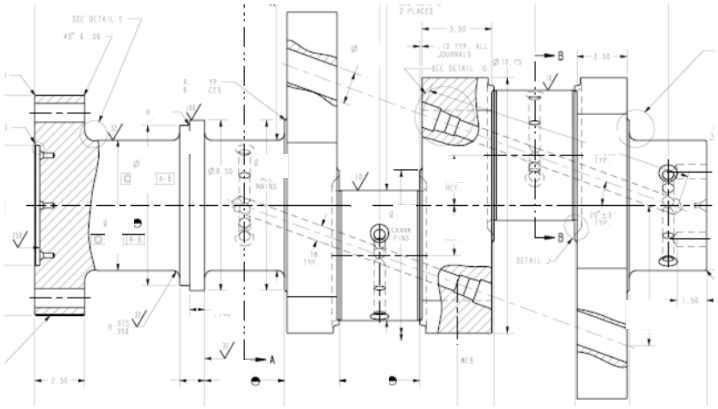


Note: ~2x reduction in POFP (on axis)



Standard Crank Drilling will pass through these high press zones.

DEF Block Change Test



Scope of design change

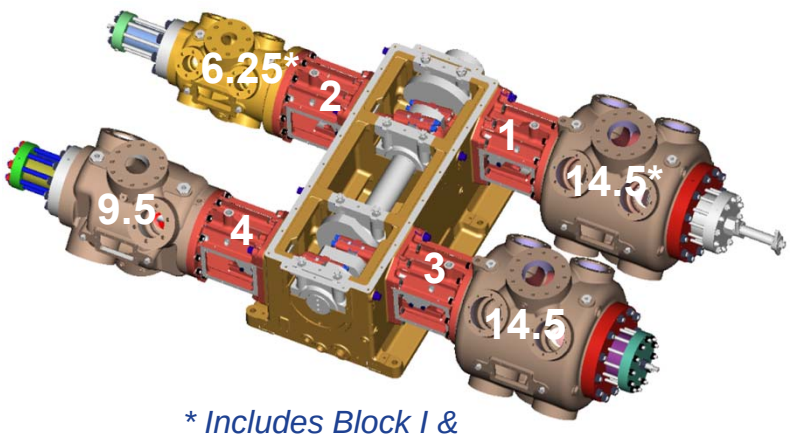
- Widen crankpin to big-end bearing contact surface to enhance the lubrication behaviour and achieve a higher degree of reliability

Crankgear components to be modified

- Crankshaft
- Crank pin bearing
- Connecting rod

Instrumentation

Skid Package • Engine Power / Torque • Crankshaft Angle, RPM • Gas Mass Flow Rate • Suction, Interstage & Discharge Press • Frame Vibrations **Lubrication System** • Oil Sump Temp • Oil Cooler Oil Inlet & Outlet Temp • Oil Cooler Coolant Inlet & Outlet Temp • Main Saddle Oil Temp, Press, Flow Rate • Main Bearing Temp, Orbits	**Throw 1** • ConRod Rifle Hole Oil Press, Temp, Flow Rate **Throw 1 vs. 3** • Crank Pin Bearing Temp, Orbit • Wrist Pin Oil Press, Orbit • Bushing Temp • Crosshead Vibration • Rod Strain • Cylinder Head & Crank End Press • VVCP Backside Press • VVCP Rod Load **Throw 2 & 4** • Cylinder Head & Crank End Press



** Includes Block I & II upgrades*

Summary

OEM/ Field issues have been resolved for high bearing reliability (99.5+% reliable) for 2+ yrs. operation; the

- Key RC manufacturer improvements (CS, cleanliness, and bearing re-certifications; test process improved).... 'the devil's in the details!'
- Packager > oil viscosity/ temperature

These and other Lessons Learned have been fed back to OEM and formally incorporated into Design Specification, vendor qualifications and Mfg work instructions

For further end user variation and confidence-

- New Babbitt (Synthec) bearing option for increased margins
- New NP-style dual feed for significant margin improvement to new units