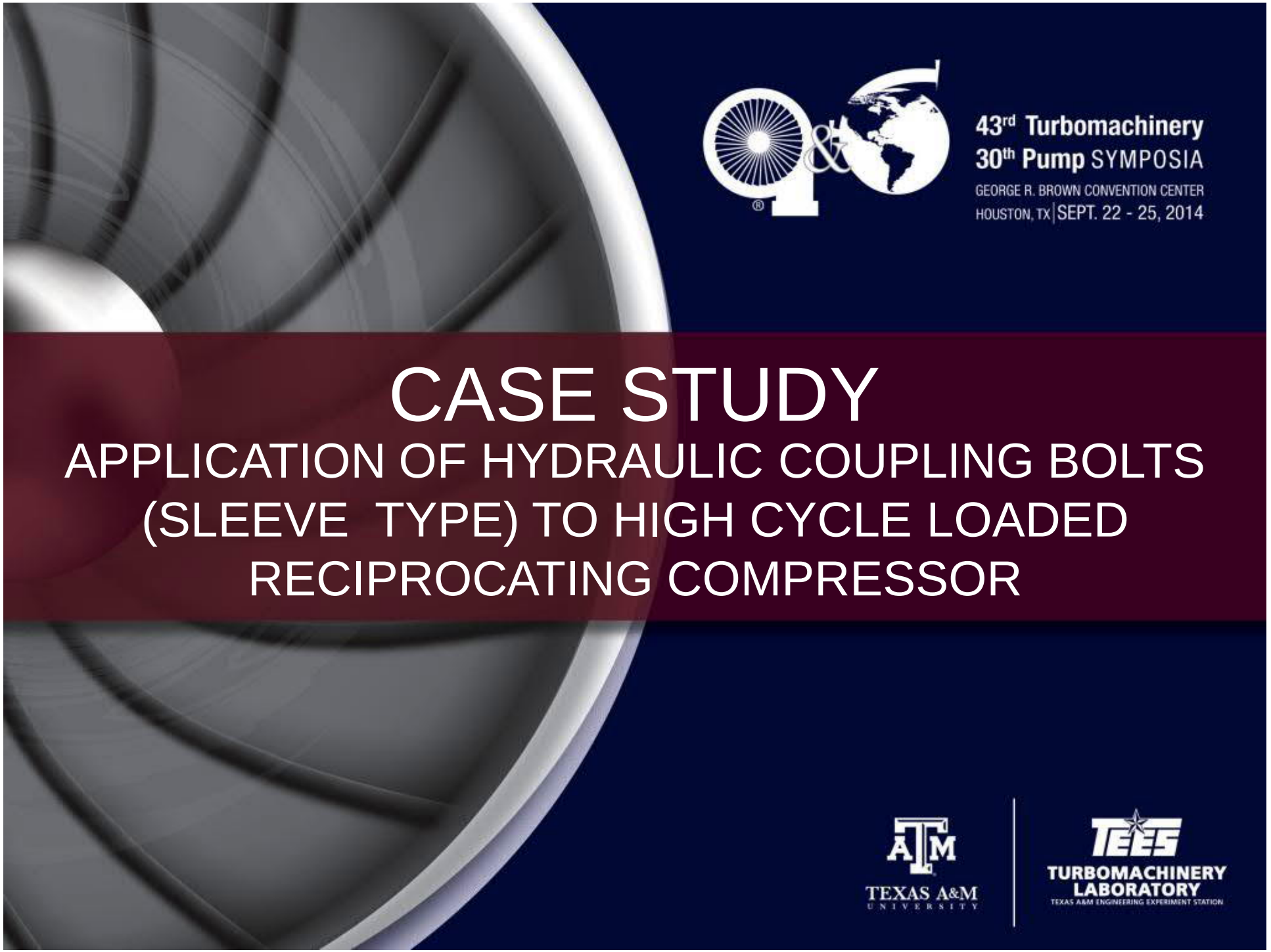

43rd Turbomachinery
30th Pump SYMPOSIA
GEORGE R. BROWN CONVENTION CENTER
HOUSTON, TX | SEPT. 22 - 25, 2014

CASE STUDY

APPLICATION OF HYDRAULIC COUPLING BOLTS (SLEEVE TYPE) TO HIGH CYCLE LOADED RECIPROCATING COMPRESSOR

TEXAS A&M UNIVERSITY

TEES TURBOMACHINERY LABORATORY
TEXAS A&M ENGINEERING EXPERIMENT STATION

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Agenda

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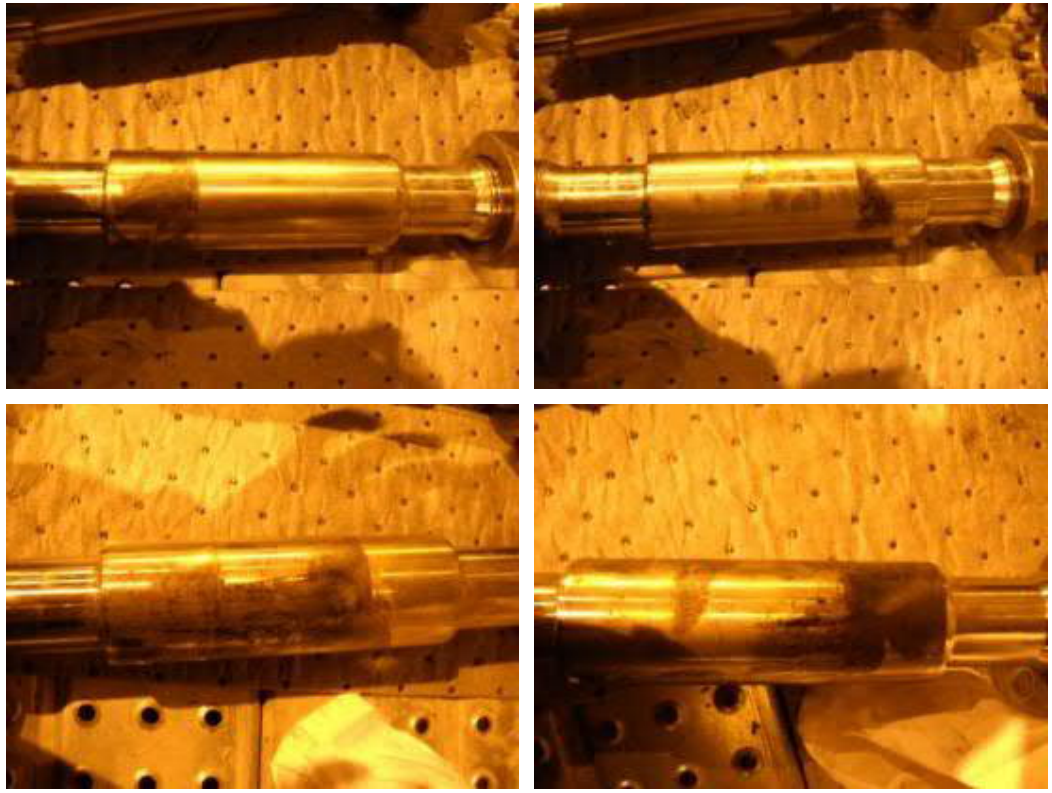
- Original Situation
  - Application description
  - Issues encountered at motor overhaul
- Potential Solutions:
  - Pros and Cons
  - Explanation of Hydraulic Bolt Concept
- Decision Made and Justification
- Results of Field Retrofit
  - Installation Procedure
  - Inspection Results & Current Status

Motor / Compressor Flanged Coupling Application Overview

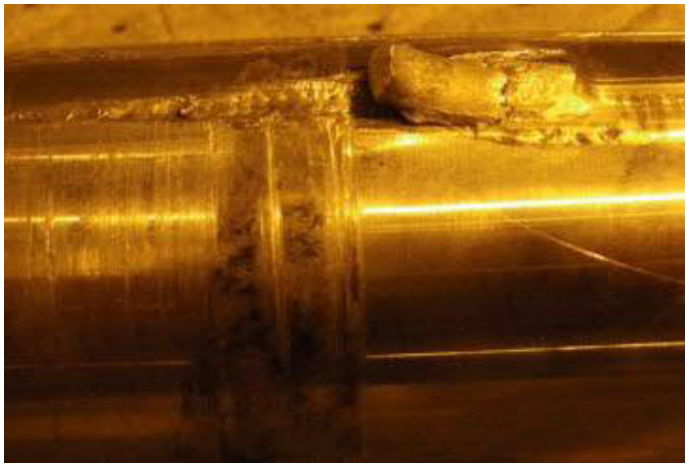
- Highly loaded reciprocating compressor type 6HG/2-1:
  - H_2 Make-up / Recycle compressor
  - ~13 MW nameplate power @ 327 rpm
  - Independent stepless regulation on the two services
- Flange coupling disassembly needed to perform corrective maintenance on motor rotor
- Connection withstands high alternating torque and rotating flexion due to flywheel and motor weight
- Coupling torque transmission predominantly by shear
- 16 fitted bolts with a tight tolerance, ϕ 60 mm

Issues Encountered at Motor Overhaul

Evidence of fretting wear on bolts

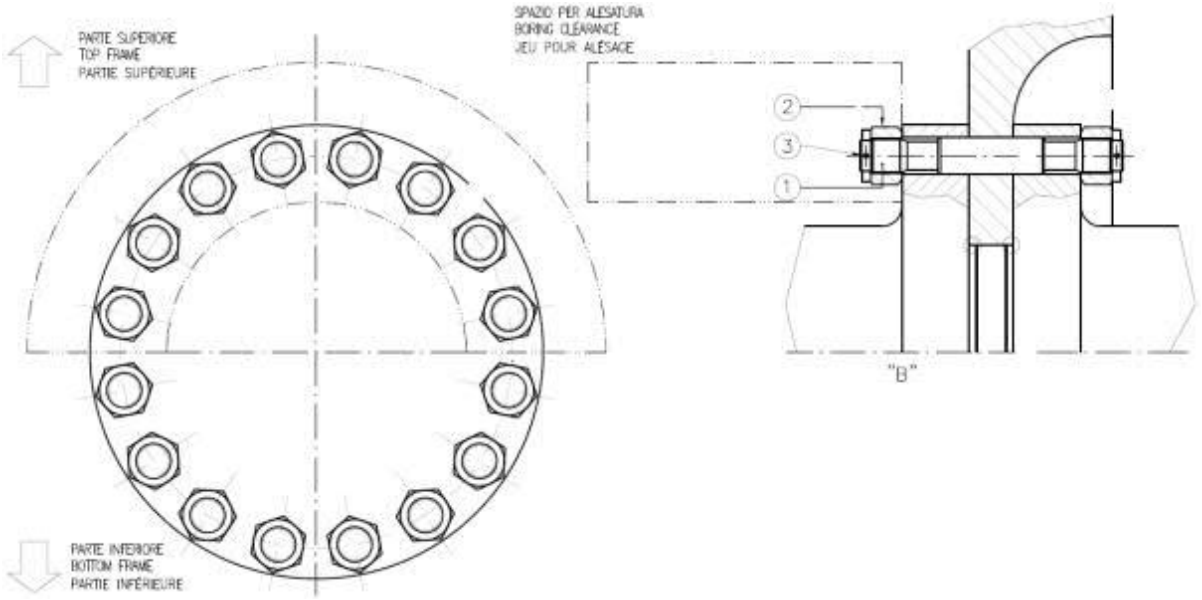


Some flange bolts & holes damaged during bolt removal



Potential Solutions

- Containment action: machining of flange holes, oversized bolts provided
- No room left for future contingencies in case further machining is needed in the future
- Corrective action: apply hydraulically fitted bolt concept



Pros & Cons of Conventional Solution

+ All-in-all, a proven and reliable solution, however, a flawless execution is required

− Low preload on bolts to preserve shear transmission

− On site reaming of flange holes
  - High precision needed, time-consuming
  - Lubrication needed for reaming, friction coefficient reduced

− Clearance variability within tolerance
  - Imperfect load sharing between bolts

− Non-conformal contact pattern
  - Possibility of slight fretting wear

− Once disconnected the flanges, bolts are not reusable and require replacement

Pros & Cons of Hydraulic Coupling Bolts

+ Reduction of downtime for reaming (needed just for holes alignment and cleaning)
+ Tolerant specs for in-field working, hand assembly
+ Effective fitting, zero clearance in operation
+ Eliminated risk of flange holes seizing
+ Equal load sharing between bolts
+ Fast assembly/disassembly
− Deep field experience with steam and gas turbines but no previous application on recip compressors

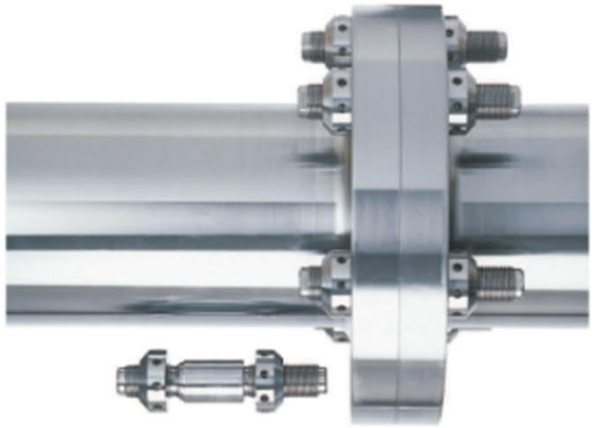
Hydraulic Coupling Bolt Concept

The hydraulic bolt consists of:

- A bolt threaded at both ends with a tapered shank
- An expansion sleeve with a corresponding tapered bore fits over the shank
- Two nuts, which complete the unit

Bolt and sleeve are clearance fit, hand assembled into bolt hole bore

Hydraulic Coupling Bolt Concept

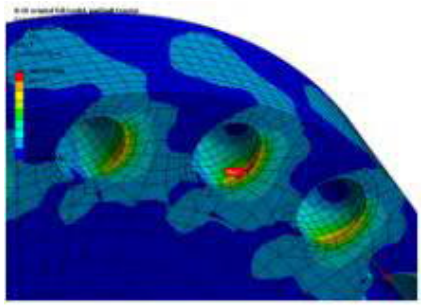


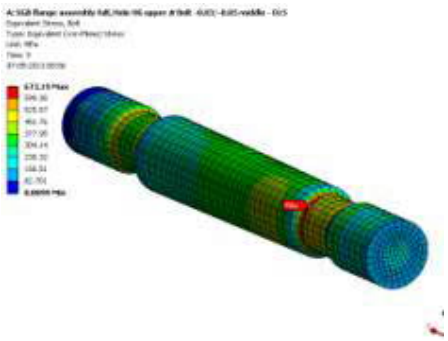
The torque is transmitted by:

- the shear strength of the expanded sleeve in the hole and the bolt itself
- the friction effect at the flange faces created by pre-loading the bolt (increased vs. standard bolts)

The combination can theoretically provide **≥** torque of original bolt design

Decision Made and Justification





Feasibility Study to confirm design parameters:

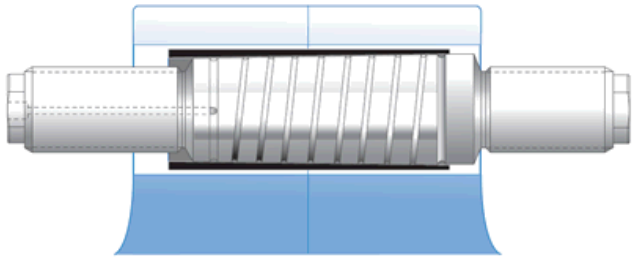
- Verification of proposed solution and comparison w/ original design margins
- All loads considered (mean/alt. torques, flywheel and motor weight)
- Detailed FEM analysis:
  - Static calculation wrt peak torque
  - Fatigue calculation wrt mean/alt. torques
  - Contact elements analysis

➢ Decision made with End User to proceed with installation after a joint Design Review

Field Retrofit Process

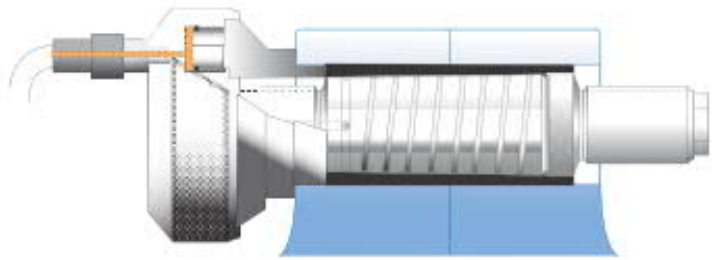
- Line boring for holes alignment and clean-up (needed at each flange disconnection)
- Sleeve OD machining on a lathe to fit the final bore dimension
- ~2 working hours for each hole / bolt preparation (at first installation)
- The complete coupling re-assembly process completed in 4 shifts time

Hydraulic Coupling Bolt - Installation



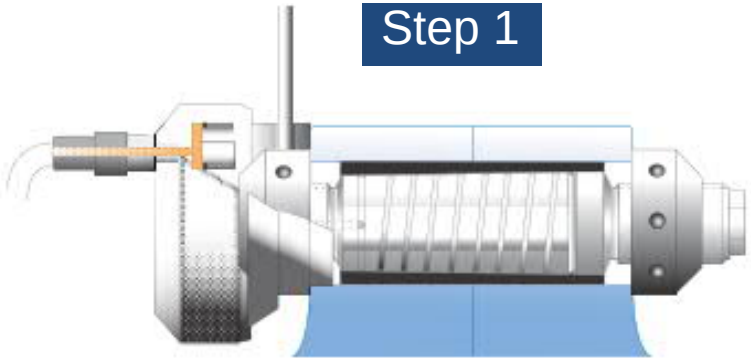
Since the bolt is initially smaller than the hole, it is easily inserted by hand.

Step 1



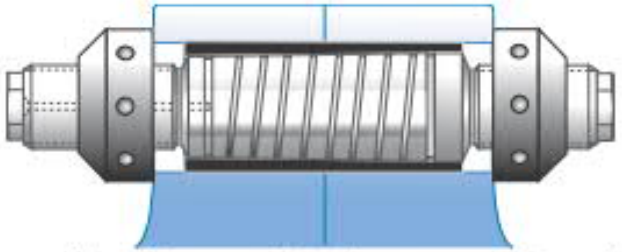
The tapered shank is drawn into the sleeve by the tensioner, creating a controlled radial interference fit.

Step 2



After mounting the nuts, the bolt is tensioned to a high axial pre-load.

Step 3



After disconnecting the pump and tensioner, the bolt is ready to transmit high torque.

Step 4

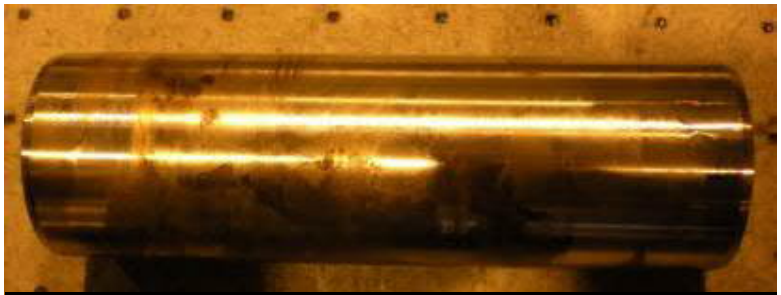
Disassembly process is reverse of the installation

- Re-usable components
- Oil injection pump w/ working pressure 150 MPa (21,300 psi)
- Typically 15 minutes per bolt

Appearance after 6,000 hours

Bolt, Sleeve and Nut after disassembly

Bolt OD (as-new condition)



Sleeve OD (minor fretting wear)

Flange Bolt Hole (no visible damage)

- After 6,000 hrs. of operation, 5 of 16 bolts were dismounted and inspected
- Visual inspection showed minor fretting wear on the sleeve OD
- NDT inspection of bolts, sleeves and flange holes showed no indications
- Returned to service seamlessly (March 2014)
- Still running today on 3 units with no issues
- Additional inspection at 12K/24K hrs planned to assess long-term wear

Q&A’s