The Evaluation of the Coefficient of Friction Used to Calculate Hub Slip Torque

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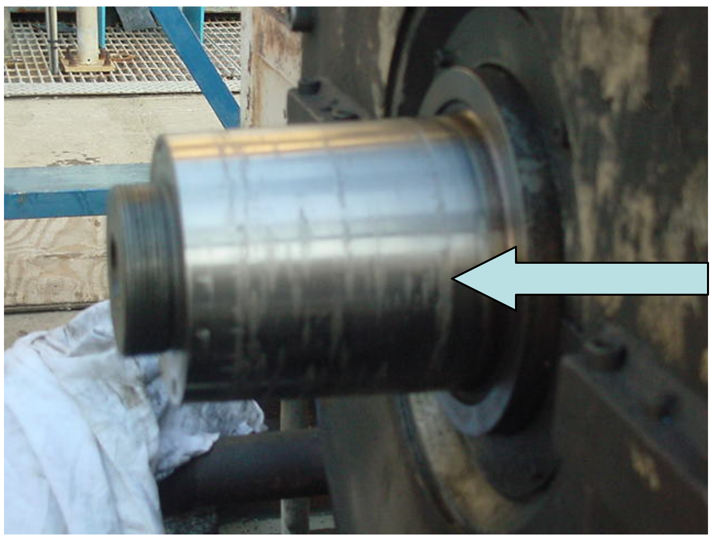
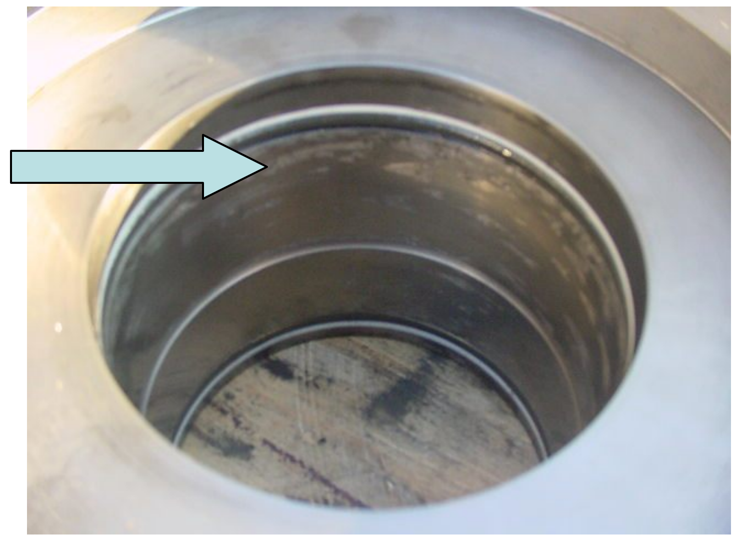
Field Problems which Initiated Testing:

- Hub slipped during operation on 3 different couplings (various size, speed, and power applications)
- Damage (galled material) on shaft end and hub:





- Effects are: costly shaft weld repair, hub replacement, unplanned outage, increased turnaround work scope

Recent Field Changes:

- Environmental Regulations recommend replacing solvent: Varsol with Acetone

  (to remove corrosion protective coating)
- Unit re-rates have dropped slip torque margins

  (margins still meet API 671- 3rd edition, 1.75x)

- Suspected reasons why hubs slipped:
  - Acetone may not properly remove corrosion protection coating
  - corrosion protection coating may lower the coefficient of friction
  - calculated slip torque values may not correspond to actual slip torque values (very important when slip torque margins are lowered)

Questions to Answer:

- How will corrosion preventive compounds affect calculated slip torque values?
- What method may be used to successfully remove the corrosion preventive compound just prior to installation?
- What is the correlation between calculated slip torque values and actual tested slip torque values?

Calculating Static Hub Slip Torque

- Step 1- Define the interference fit and calculate the pressure required to overcome it

$$p = \frac{I_{\max} E(1 - C_e^{\,2})}{2D_b}$$

AGMA 9003-A91 (Eq. 4.4)

Where:

I_{max} = specified interference fit (in)

E = Young's Modulus (lb/in^2)

C_e = ratio of average bore diameter to outside diameter

D_b = bore diameter (in)

Calculating Static Hub Slip Torque

- Step 2- Solve for slip torque using the calculated pressure from Step 1

$$T = \frac{p \pi D_b^{\,2} L \mu}{2}$$

AGMA 9003-A91 (Eq. 4.1)

Where:

p = pressure required to break the interference fit (psi)

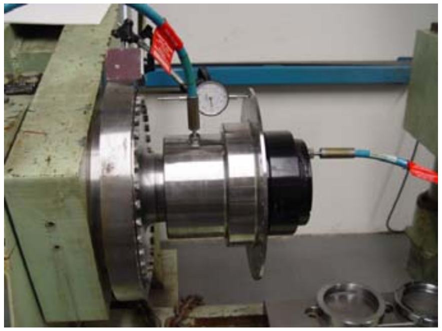
D_b = average bore diameter (in)

L = length of hub engagement (in)

μ = apparent coefficient of friction

Test Components

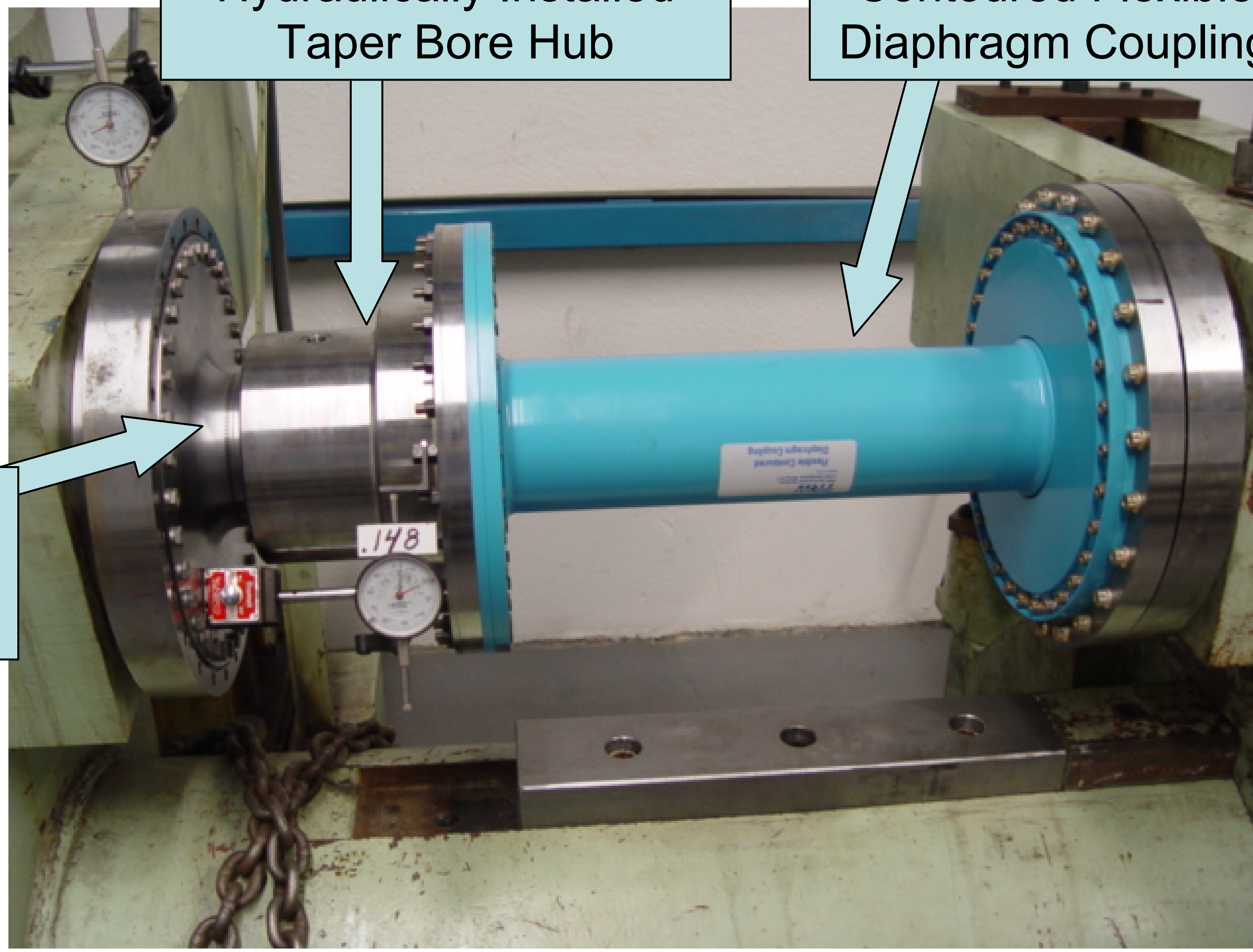
- Replicated Machinery Shaft End
- Hydraulically Installed Taper Bore Hub
  - With 2 Buna-N O-Rings & 2 Teflon Back Up Rings
- Contoured Flexible Diaphragm Coupling (to take up misalignments in test equipment)



Test Equipment

- Million-Inch Pound Static Torque Test Stand

Test Set-Up


Hydraulically Installed Taper Bore Hub
Contoured Flexible Diaphragm Coupling
Replicated Machinery Shaft End
.148

Test Conditions- Corrosion Protection Coating

- Test #1 & 2 = .002 in/in interference ratio
- Test #3 & 4 = .0025 in/in interference ratio

- Constant conditions for all 4 tests:
  - Corrosion protection coating (Dow MOLYKOTE® Metal Protector Plus) applied to hub bore
  - Shaft end was left bare (dry metal)

Results- Test #1-4

- Hub could not be installed on shaft end (coating did not provide friction fit)
- No slip torque data was obtained

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Test Conditions- Clean with Acetone

- Test #5 = .002 in/in interference ratio
- Test #6 = .0025 in/in interference ratio

- Constant conditions for both tests:
  - Remove corrosion protection coating (Dow MOLYKOTE ® Metal Protector Plus) on hub bore with Acetone
  - Shaft end was left bare (dry metal)

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Test Conditions- Clean with Solvent WD-40

- Test #7 = .002 in/in interference ratio
- Test #8 = .0025 in/in interference ratio

- Constant conditions for both tests:
  – Remove corrosion protection coating (Dow MOLYKOTE ® Metal Protector Plus) on hub bore with Solvent WD-40
  – Shaft end was left bare (dry metal)

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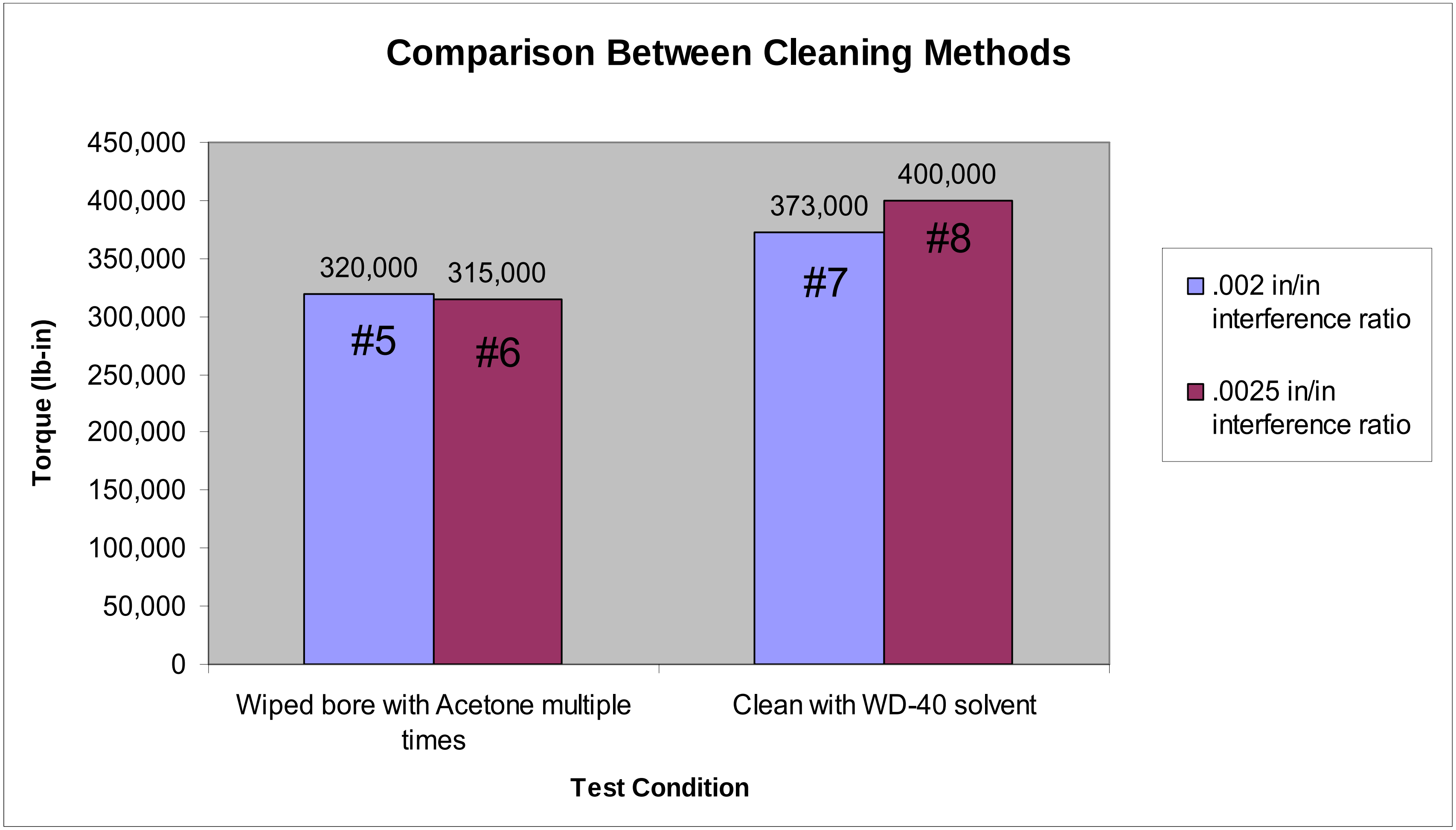
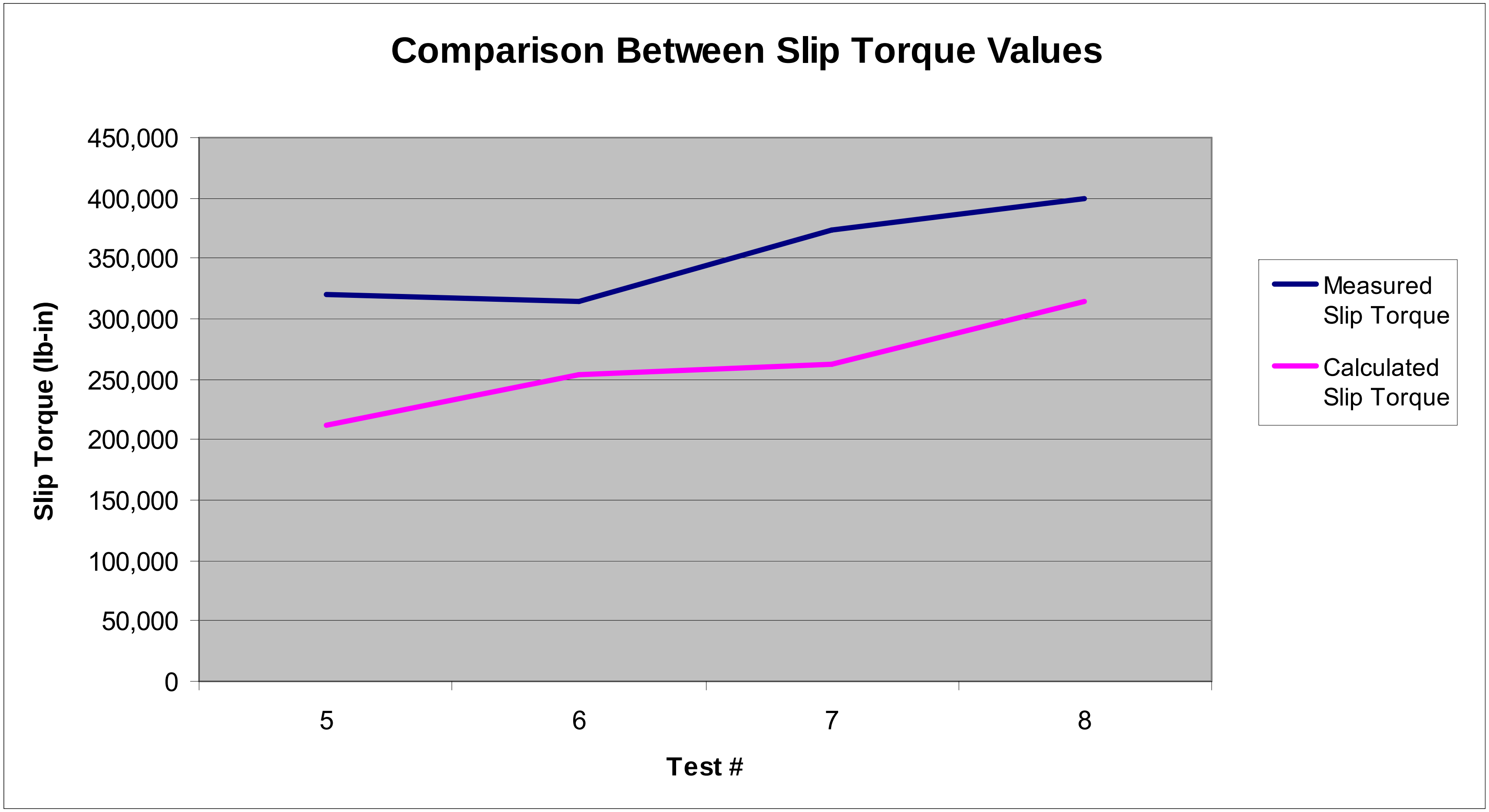
Results (Tests #5-8)



Note: data is based on newly machined components in a clean environment

Results (Tests #5-8)

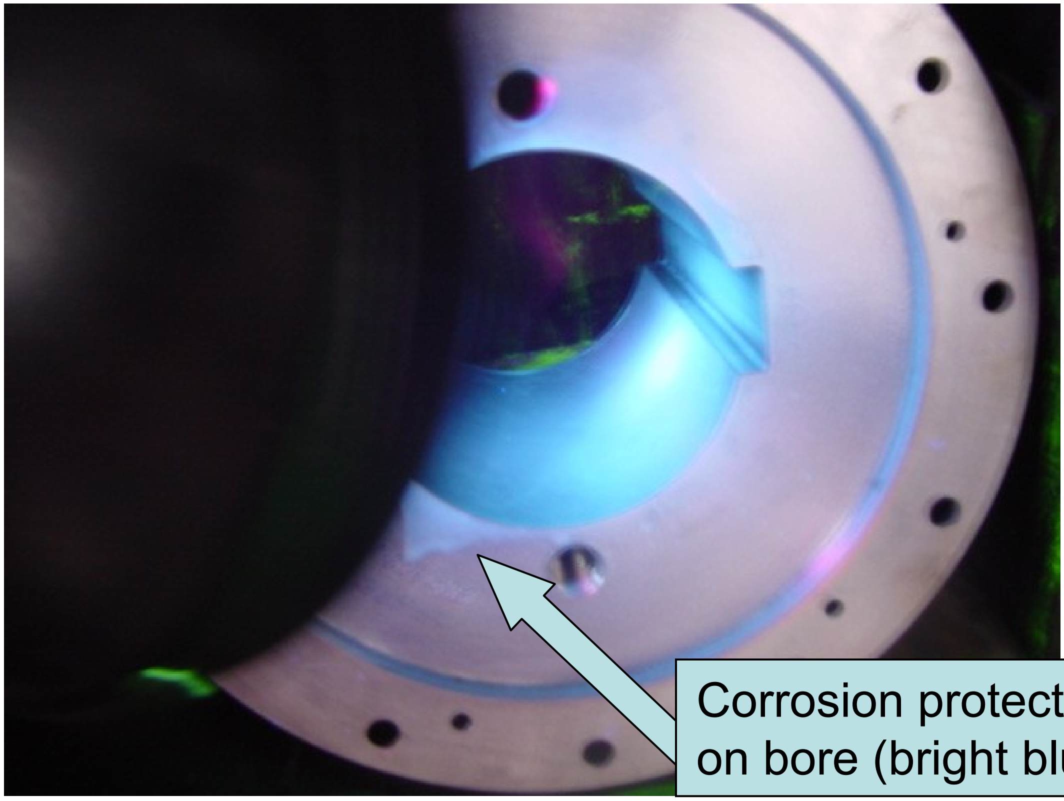


Coefficient of friction solved from actual test data = 0.18 average

Note: data is based on newly machined components in a clean environment

Black Light Test

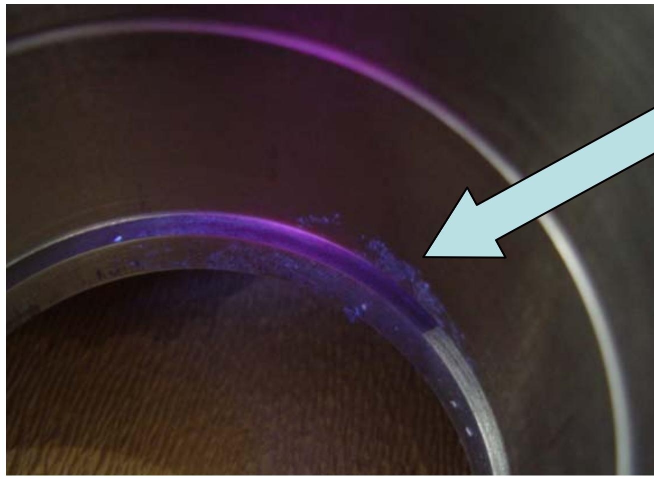
- Hub as received from manufacturer- with corrosion protection coating



Corrosion protection coating on bore (bright blue finish)

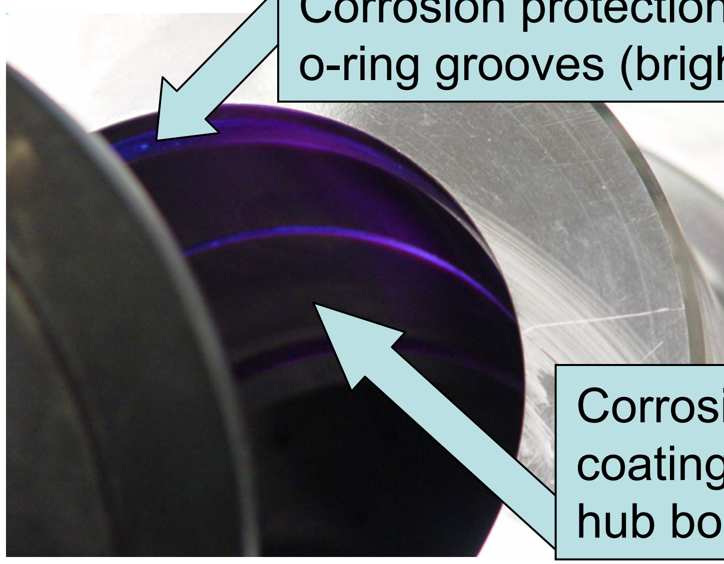
Black Light Test

- Clean with Acetone & coating still remains



Corrosion protection coating still remains on bore (bright blue finish)

- Clean with solvent WD-40 & coating is fully removed



Corrosion protection coating still remains in o-ring grooves (bright blue finish)

Corrosion protection coating removed from hub bore (dark finish)

Conclusions

1. Corrosion preventive compounds (Dow MOLYKOTE ® Metal Protector Plus) can affect slip torque values
2. Cleaning methods can affect slip torque values
3. Calculated slip torque values for the tests conducted were lower than actual slip torque values:

Using:

$\mu = 0.12$, for corrosion protection coating (Tests #5 & 6)

$\mu = 0.15$, for hydraulically installed steel to steel parts (Tests #7 & 8)

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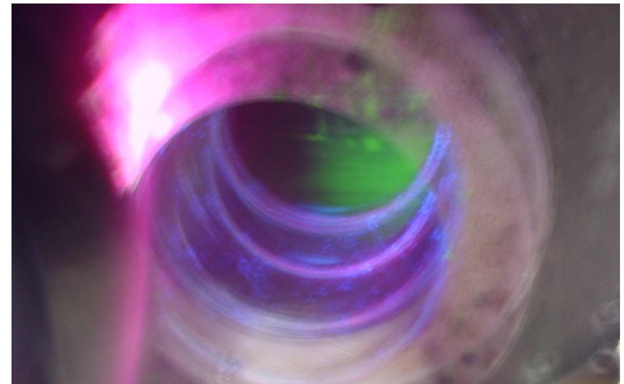
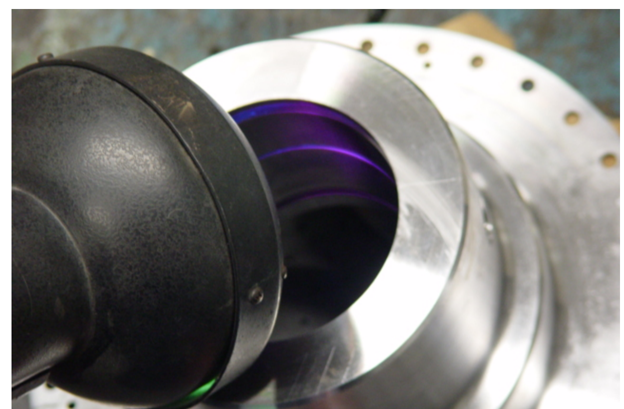
Recommendations

1. Contact manufacturers to identify what corrosion protection coatings are applied to parts.
2. Determine the best method for removing the corrosion protection coating, and if possible, develop a procedure to verify cleanliness.
3. Clearly define hub installation techniques to establish a procedure for consistent, repeatable results.



Corrosion protection coating still remains



Effectively cleaned hub