

**2016 STLE Annual Meeting
Power Generation Industrial Council**

MOV Grease Evaluations With a Modified 4-Ball Wear Test

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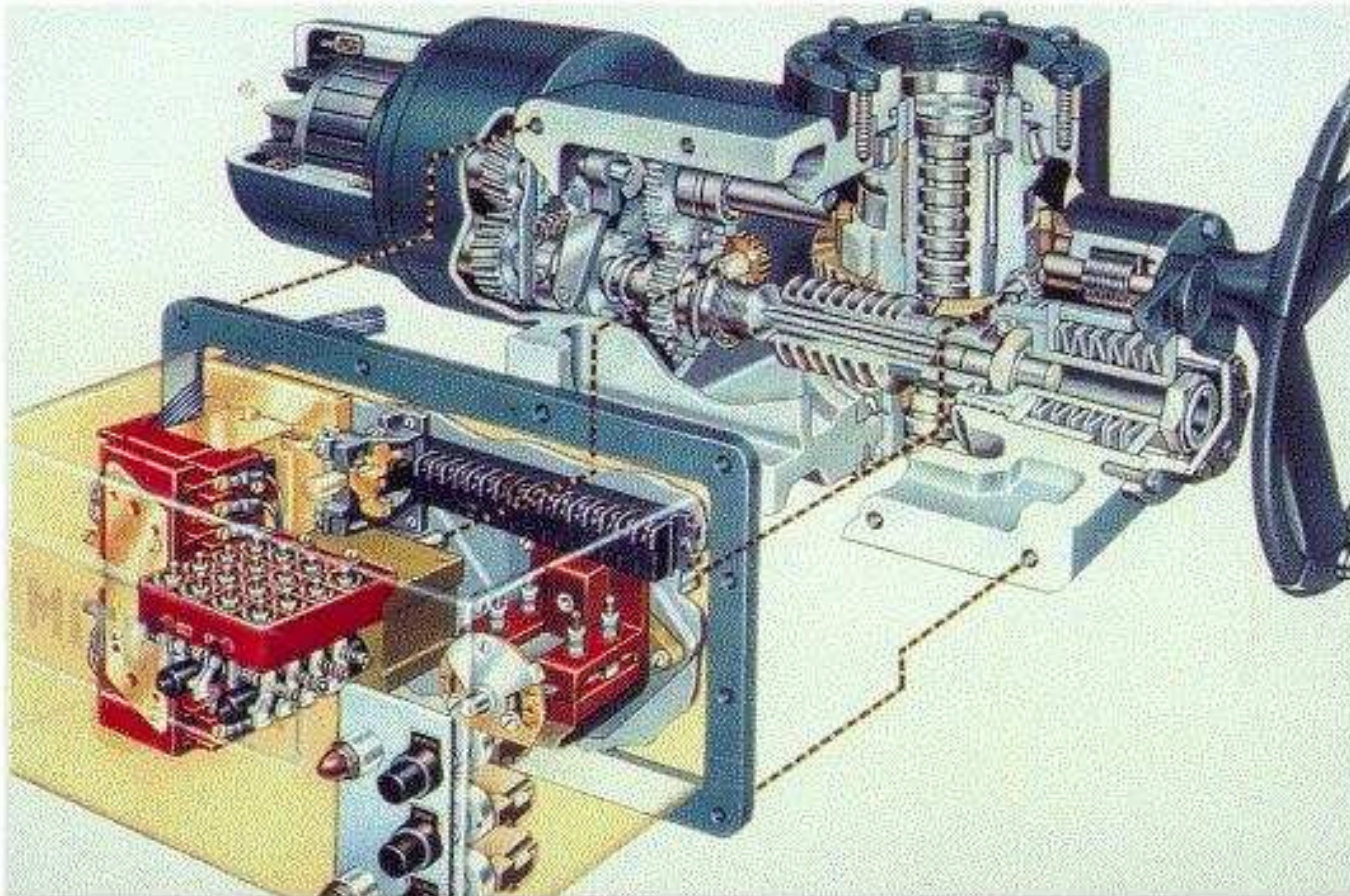
Abstract

MOVs (motor operated valves) are used by the hundreds in power stations because they can be remotely operated. They are motor driven generally with integral gearboxes that can be grease lubricated. The same grease can also be used to lubricate the valve stem. Some of the important tribo components including the worm and stem nut are made of copper alloys.

Abstract

Some stations had reported OEs (operating events) because of excessive stem nut wear so the concern was whether the greases being used and the testing was adequate. For example, many of the standard wear tests use steel specimens which might not be suitable for the bronze stem nuts and stainless steel stems. Consequently the 52100 steel balls in ASTM D2266 were replaced with bronze and stainless steel balls.

Limitorque SMB



EPRI Stem Nut Grease Survey

| Grease | Users % |
|----------------------------|---------|
| Calcium Complex | 26 |
| Nickel Antiseize Compound | 24 |
| EP Lithium Soap | 16 |
| Clay Synthetic Hydrocarbon | 14 |
| Other Types | 20 |

- Ref: EPRI Lube Note #1 Dec 1996

Stem Nut Wear

Stem Nut Wear, Antiseize

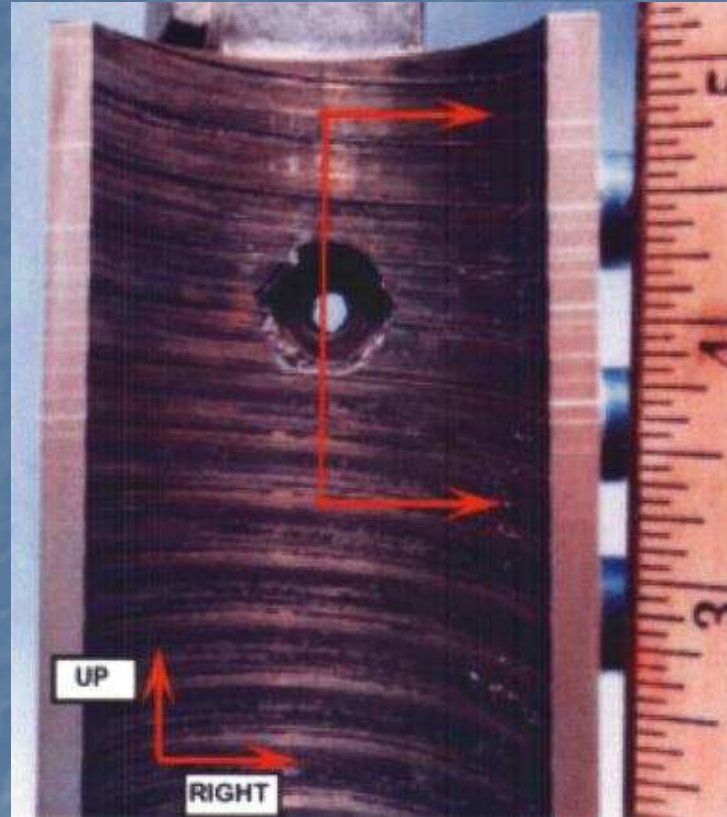
- RHR Minimum Flow Valve (SB-00, 1.25" Diameter)



Significance

- Proper lubrication of the stem/stem nut is important to achieve consistent torques and to lubricate the working surfaces.
- While the requirements for a good gearbox lubricant are given, those for the stems are less clearly defined.
- One concern is that a worn stem nut could fail badly if the teeth strip.

Worst Case?



**Alaska Airlines Flight 261
Stripped ACME Thread Stabilizer Nut
Aluminum Bronze – Clay Thickened Greases**

Nuclear Power Stations

MOVs are also used to control, open or close valves on both the steam and water systems at nuclear power stations.

Some of these can be on safety related systems so that suitable greases must also be qualified to prove that they and/or the equipment remains functional after a design basis accident.

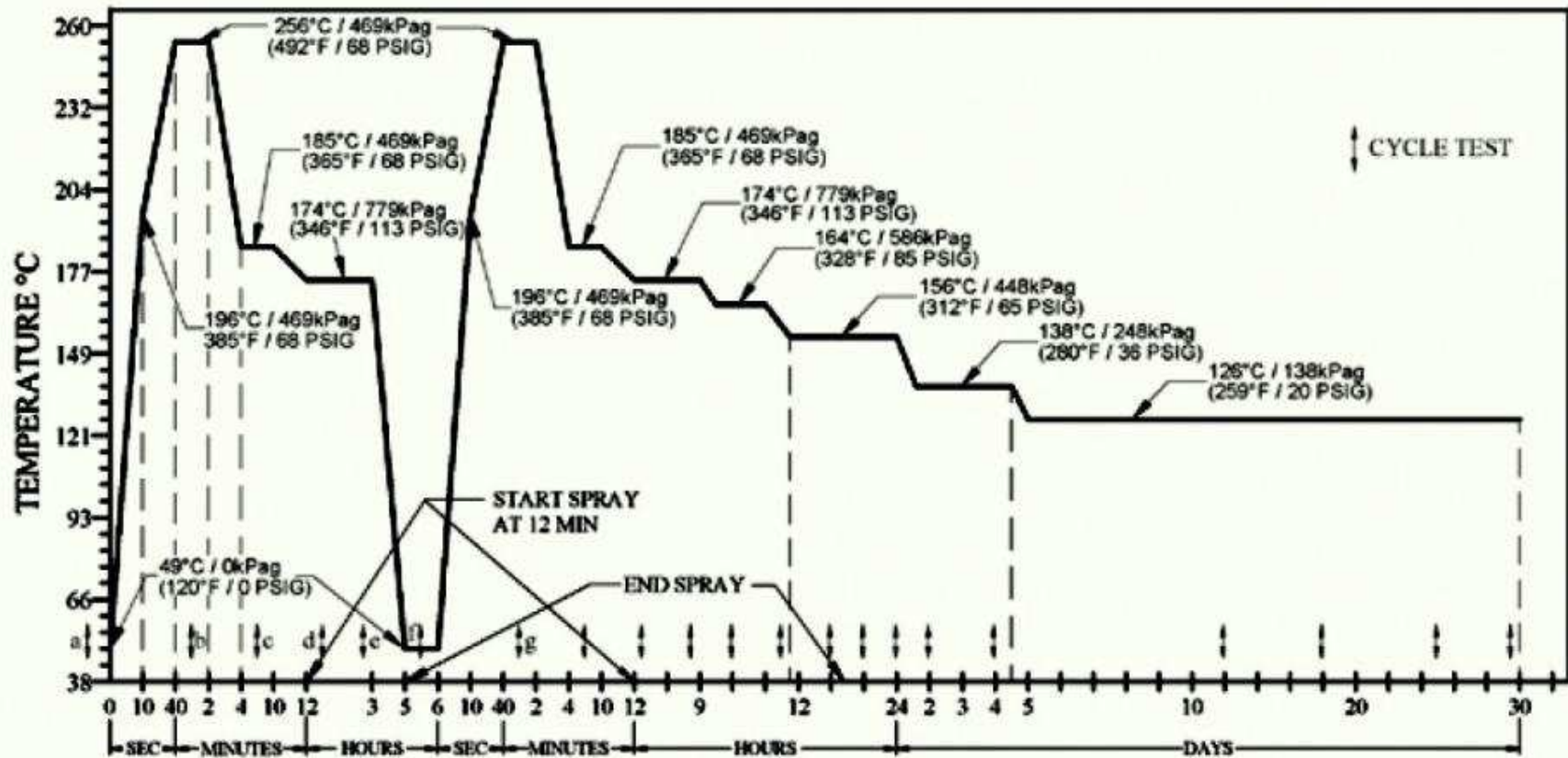
Each batch of grease must also be given commercial grade dedication to prove what was received was what was ordered and was made correctly.

Design-basis accident

“A postulated accident that a nuclear facility must be designed and built to withstand without loss to the systems, structures, and components necessary to ensure public health and safety.”

Ref: <http://www.nrc.gov/reading-rm/basic-ref/glossary/design-basis-accident.html>

Design-basis Accident Conditions



Nuclear Power Stations

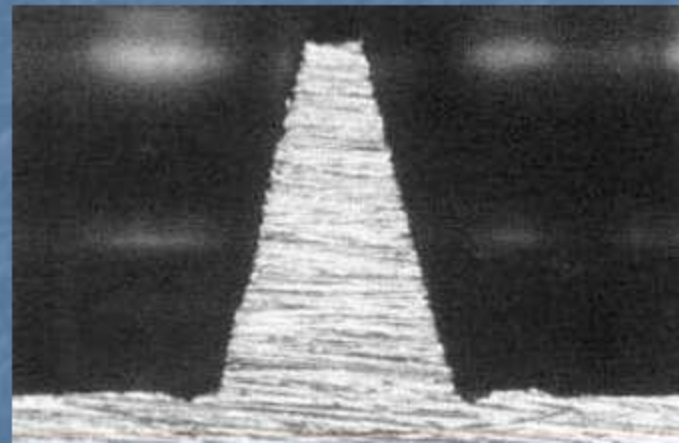
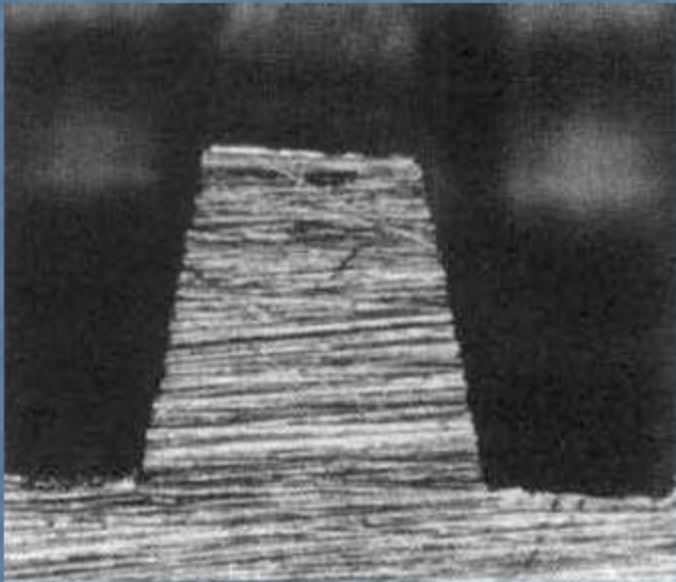
Because lubricants used on safety related systems require a rigorous approval process there is sometimes a tendency to use an EQ'd lube already in use in other applications. This can be one reason why anti-seize pastes might be used as a lubricant. Another contributing factor can be a lack of proper training about lubricants.

NRC Instruction Notices

- IN 2006-29: 'Potential Common Cause Failure of Motor-operated Valves as a Result of Stem Nut Wear' re Susquehanna
- IN 2010-03: 'Failures of Motor-Operated Valves Due to Degraded Lubricants' re Peach Bottom, Vogtle and Callaway.

EPRI

(Electric Power Research Institute)



Bronze stem nut from a SMB 000 after 6 years of service using different lubricants.

Ref: EPRI Lube Note #3 May 1990

EPRI

The actuator grease traditionally used by stations and by a major OEM was a calcium complex. This had the tendency to age harden so alternatives were being evaluated.

The goals were to find a better grease, one that meet the OEM requirements, one that could be used in all three grease applications and preferably one that was compatible with the current grease.

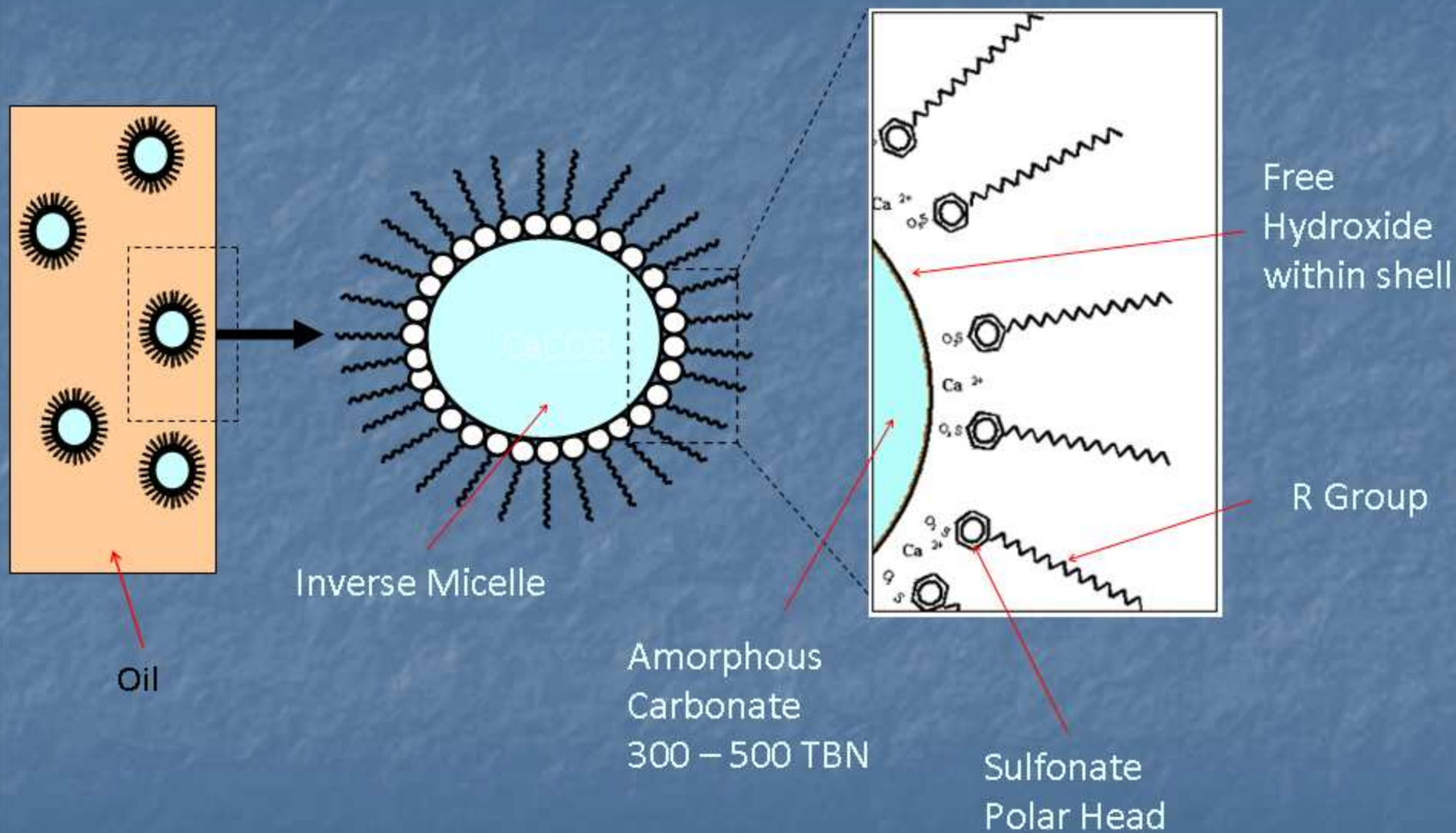
EPRI

Working with them a number of calcium sulfonate complex greases were tested and the one eventually qualified has a Group II basestock.

Some advantages included;

- High Dropping Point
- Good Water Resistance
- Excellent Mechanical Stability
- Excellent Corrosion Prevention
- Low Wear
- High EP

Overbased Calcium Sulfonate



Grease/Paste Components

| | Description |
|--------------|--|
| CSC Group II | Calcium sulfonate complex (also CCS) |
| CSC Group I | Calcium sulfonate complex (also CCS) |
| Ca Complex | Calcium complex, hydrotreated naphthenic oil |
| Clay PAO | Clay thickener and synthetic hydrocarbon (PAO) |
| Li 12 | Lithium hydroxystearate thickener, highly refined oil, zinc dithiophosphate, 'chlorinated paraffins' |
| Li 12 Cl | Lithium thickener, hydrotreated naphthenic oil, zinc oxide, antimony dithiocarbonate |
| Ni Paste | White oil (30-60%), nickel (10-30%) and graphite (10-30%) |
| Ca Paste | White oil (30-60%), calcium oxide (10-30%) and graphite (10-30%) |

Test Grease/Paste Characteristics

| | NLGI Grade | Penetration 60 Strokes | Base Oil Viscosity | |
|-----------------------|------------|---------------------------|--------------------|-------|
| | | | 40°C | 100°C |
| CSC Group II | 0 | 370 | 95 | 10.8 |
| | 1 | 325 | 95 | 10.8 |
| | 2 | 280 | 95 | 10.8 |
| CSC | 0 | 375 | 23.4 | 4.7 |
| | 1 | 325 | 23.4 | 4.7 |
| Ca Complex | 0 | 370 | 96.3 | 8.3 |
| | 1 | 325 | 96.3 | 8.3 |
| Clay PAO Grade | 1½ | 295 | 29.3 | 5.6 |
| Ni Paste | ~0-1 | 300-390 | ? | ? |
| Ca Paste | ~0-1 | 325-375 | ? | ? |

ASTM D2509 Timken Wear Tester



Timken Ring On Block

Timken Okay Load Results

| | kgf | lb |
|-----------------------------|-------------|-----------|
| CSC Group II Grade 0 | 24.9 | 55 |
| Grade 1 | 27.2 | 60 |
| Grade 2 | 27.2 | 60 |
| CSC Grade 0 | 22.7 | 50 |
| Grade 1 | 25 | 55 |
| Ca Complex Grade 0 | 21 | 45 |
| Grade 1 | 21 | 45 |
| Clay PAO Grade 1½ | 5.4 | 12 |

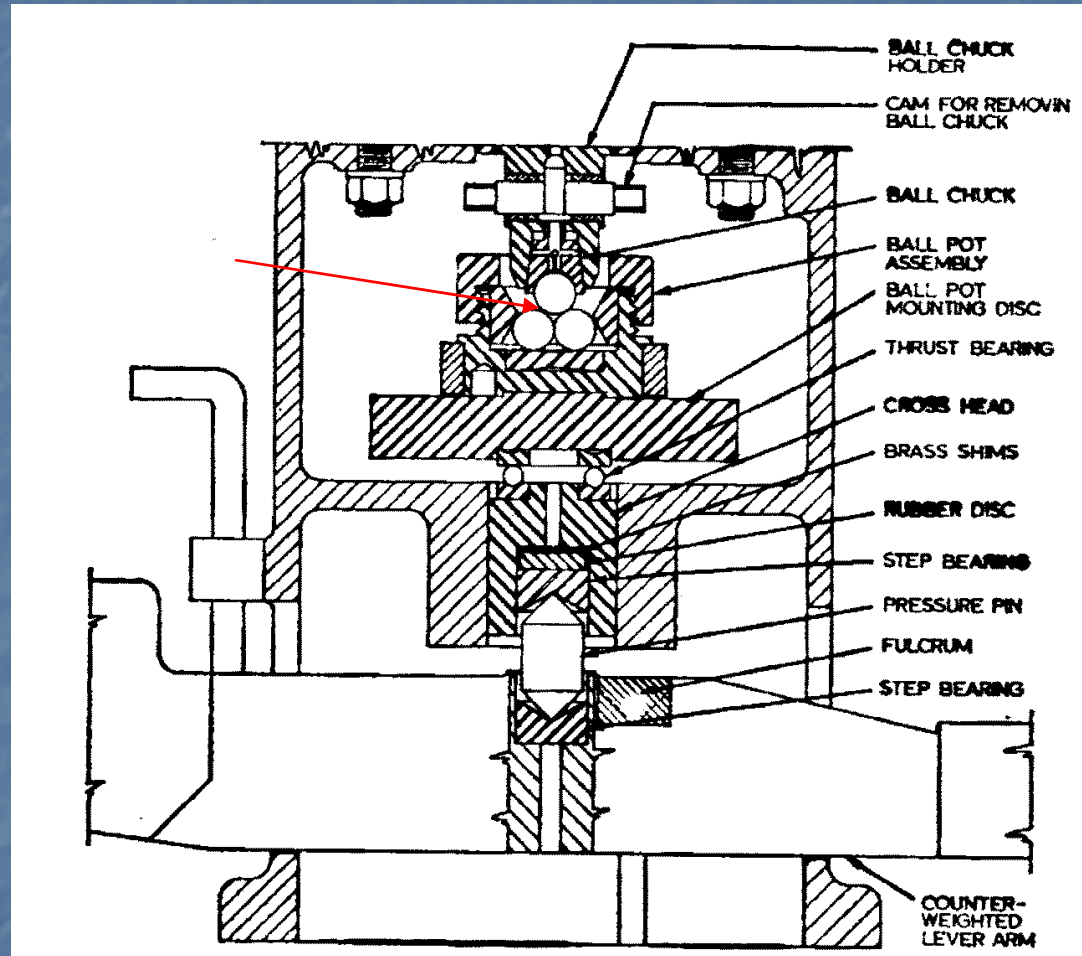
Data Sheet Values

ASTM D2266-01 Standard Test Method For Wear Preventive Characteristics Of Lubricating Grease (Four-Ball Method)

This test method covers the determination of the wear preventive characteristics of greases in sliding steel-on-steel applications.

- Wear is reported as the diameter of the wear scar. Smaller is better.

ASTM D 2266 4-Ball Wear Test



ASTM D2266 4-Ball Wear Tester



Previous 4-Ball Wear Data Effect of Test Temperature

| Grease | ASTM D-2266 4-Ball Wear (mm) | | |
|---|------------------------------|-------|-------|
| | 75°C | 150°C | 225°C |
| Li 12 Cl EP1 | 0.45 | 0.50 | 0.84 |
| Li Complex EP2 | 0.50 | 0.60 | 0.68 |
| Ca Complex EP1 | 0.57 | 0.71 | 1.06 |
| CSC Group II | 0.49 | 0.54 | 0.48 |
| CSC (calcium sulphonate complex) has more consistent results | | | |

Previous 4-Ball Wear Coefficient Of Friction

| Earlier Data | | | | |
|--|---------|----------------------|--------|--------|
| | | Friction Coefficient | | |
| | | 75° C | 150° C | 225° C |
| Li 12 Cl EP1 | Start | 0.097 | 0.099 | 0.071 |
| | Running | 0.119 | 0.124 | 0.106 |
| Li Complex EP2 | Start | 0.076 | 0.079 | 0.057 |
| | Running | 0.102 | 0.081 | 0.077 |
| Ca Complex EP1 | Start | 0.113 | 0.1 | 0.096 |
| | Running | 0.124 | 0.119 | 0.145 |
| CSC Group II | Start | 0.1 | 0.098 | 0.099 |
| | Running | 0.09 | 0.085 | 0.085 |
| CCS (Calcium Sulphonate Complex) Grease Shows Less Change | | | | |

4-Ball Wear (2006 MUG Meeting) Effect of Aging

| Product | ASTM D-2266 4-Ball Wear Scar (mm) |
|--|--|
| New CSC Group II | 0.45 |
| 300 Hours Aged | 0.43 |
| 450 Hours Aged | 0.45 |
| 600 Hours Aged | 0.44 |
| Aging was done at 150°C (300°F). Little Change For CSC (calcium sulphonate complex) | |

| | CSC 1 | CSC II 1 | Ca Complex 1 | Clay PAO | Ni Paste | Ca Paste |
|-------------|-------|----------|-----------------|----------|----------|----------|
| Aluminum | 28 | 17 | 38 | 8240 | 3380 | 141 |
| Copper | <1 | <1 | 1 | <1 | 3 | 4 |
| Iron | 25 | 19 | 52 | 1651 | 133 | 100 |
| Tin | 13 | <1 | <1 | 4 | 17 | 2 |
| Chromium | <1 | <1 | 1 | <1 | 3 | 3 |
| Lead | 11 | 1 | <1 | 26 | 193 | 4 |
| Cadmium | <1 | <1 | <1 | <1 | <1 | <1 |
| Nickel | 7 | 1 | <1 | <1 | 129422 | 117 |
| Titanium | 5 | 2 | <1 | 31 | 10 | 6 |
| Zinc | <1 | <1 | 7 | 3 | 349 | 17 |
| Phosphorous | <1 | 218 | 758 | 333 | <1 | 20 |
| Molybdenum | 3 | 3 | 1 | 5 | 6 | 2 |
| Calcium | 56496 | 59159 | 55989 | 3887 | 1838 | 98965 |
| Barium | 31 | 24 | 56 | 1 | 8 | 10 |
| Magnesium | 96 | 57 | 217 | 831 | 11 | 351 |
| Boron | 2746 | 2414 | <1 | 6 | 19 | 17 |
| Sodium | 65 | 28 | 101 | 2817 | 50 | 99 |
| Silicon | 58 | 30 | 372 | 18788 | 55 | 353 |

Total metals analysis by ICP scan with Ashing and Acid digestion (ppm)

ASTM D2266 4-Ball Wear Results

| | Data Sheets | Test Data |
|-----------------------|-------------|-----------|
| | mm | mm |
| CSC II Grade 0 | 0.49 | 0.49 |
| Grade 1 | 0.49 | 0.47 |
| Grade 2 | 0.49 | 0.40 |
| CSC Grade 0 | 0.48 | - |
| Grade 1 | 0.38 | 0.42 |
| Ca Complex EP0 | 0.67 | - |
| EP1 | 0.67 | 0.47 |
| Clay PAO | 0.5 | 0.52 |
| Paste Ni | - | 0.75 |
| Paste Ca | - | 0.69 |

ASTM G99 Pin on Disc

Bronze Pin and 310 SS Disc

| Grease | Avg. Coef. of Friction x 100 | Pin Scar Dia. mm x 100 | Disc Scar Dia. mm x 100 |
|---------------|-------------------------------------|-------------------------------|--------------------------------|
| Li Diester | 10 | 72 | 36 |
| Clay PAO | 12 | 72 | 34 |
| CSC Group II | 11 | 30 | 15 |

Ref: EPRI Lube Notes Nov 2002

New 4-Ball Wear Testing

- The standard test uses ½” 52100 steel balls.
- These were changed to balls made of 3600 brass and 302 stainless steel.

New 4-Ball Wear Testing - Brass and Stainless Steel Balls

| Grease | Wear Scar (mm) |
|------------------------------|----------------|
| Ni Paste | 2.63 |
| Ca Paste | 2.40 |
| Clay PAO | 1.73 |
| Li 12 CI EP2 | 1.55 |
| Li Grade 1 ("high antiwear") | 1.43 |
| CSC Group II Grade 1 | 1.05 |

15 kg, 1200 rpm, 75°C (167°F), 60 minutes

New 4-Ball Wear Testing

- CSC Group II Grade 2 1.17 mm
- CSC Group II Grade 1 1.05 mm
- CSC Group II Grade 0 0.88 mm

Brass and SS at 15 kg, 1200 rpm, 75°C, 60 minutes

Antiwear, Antiscuff, EP?

- It used to be that an extreme pressure (EP) grease was all that was required but this term is not clear.

It was thought that an EP grease was one with a Timken Okay Load ≥ 15 lb or in the 4-ball EP test anything over a 200 kg weld point.

In which case over half of the grease/pastes being used might be borderline.

Summary

1. A test using more representative materials has been developed. This showed that greases with the calcium sulphonate thickener system provided less wear when compared to other greases and pastes.
2. If greases or pastes with solids OR a product showing higher wear rates are being used OR were used, it might be appropriate to assess the stem nut wear.