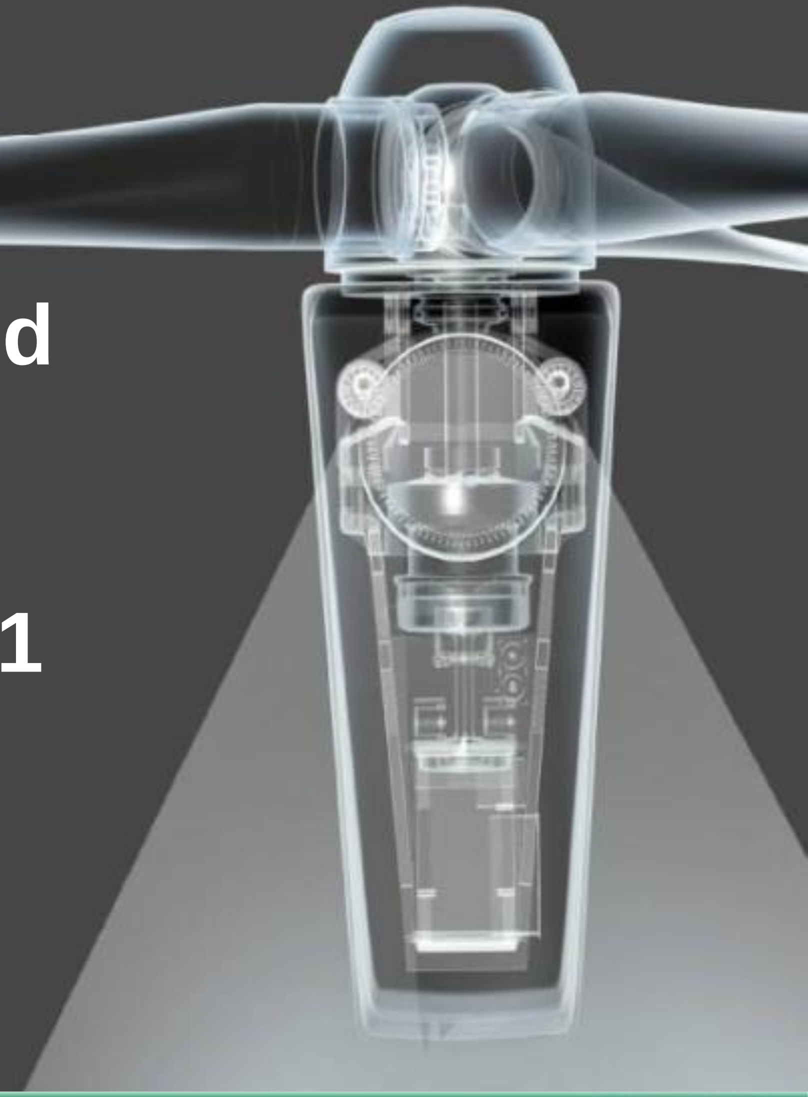
Grease Technology in Wind Turbine Applications

Castrol Tribol GR SW 460-1



Presented by:

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III Wind Farm Operators Forum
Gdansk, 13-14th March 2019

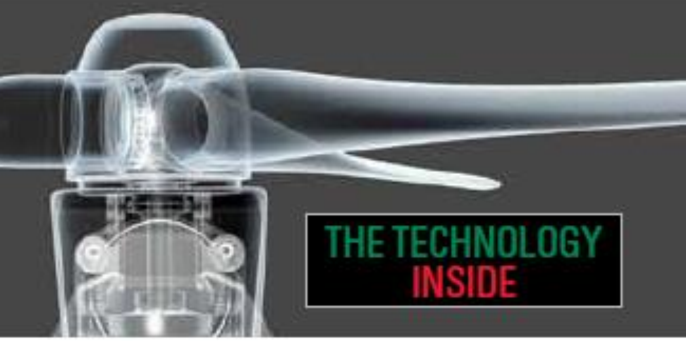
IT'S MORE THAN JUST OIL. IT'S LIQUID ENGINEERING.

Castrol Industrial

Agenda

- Main Bearing Reliability - Context
- Grease Composition
  - ✓ Base Oils
  - ✓ Additives
  - ✓ Thickening Systems

- Grease Benchmarking
- Wind Turbine Applications and Challenges
- Product Development
- Grease Changeover Procedure
- Main Bearing Grease Analysis



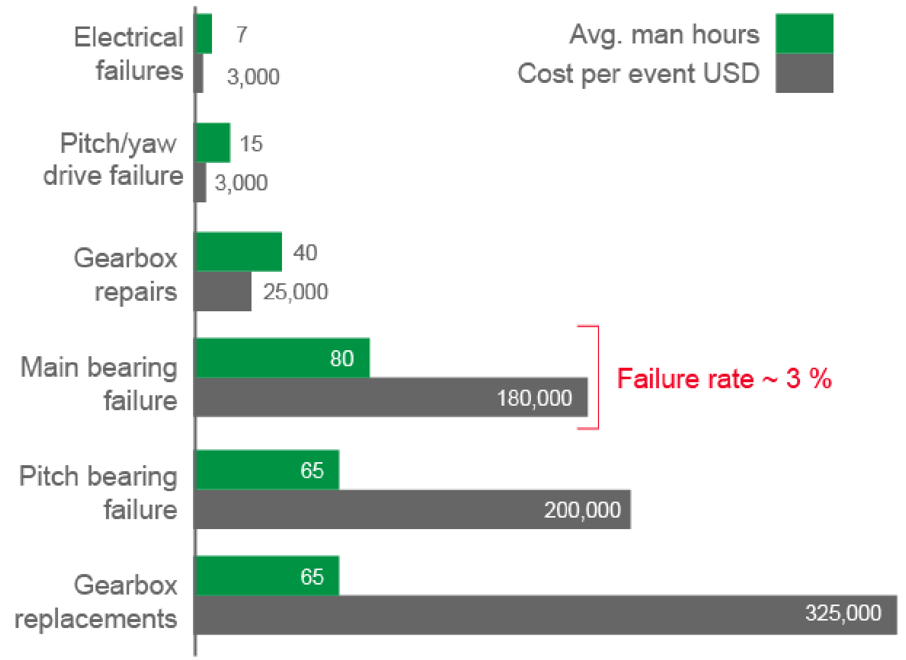
BEARINGs MAINTENANCE COST
PLANNED VS UNPLANNED MAINTENANCE

THE TECHNOLOGY INSIDE

Semi annual/annual planned maintenance

EVOLUTION	COST	TIME
Grease pitch and yaw bearings		
Grease main bearing	USD 600 per wind turbine generator	12 man-hours
Grease generator bearings		

Cost of component failures (hours/USD):



Source; MAKE

Improved Maintenance
Increases Reliability

Monitor:

- You can’t improve what you don’t measure

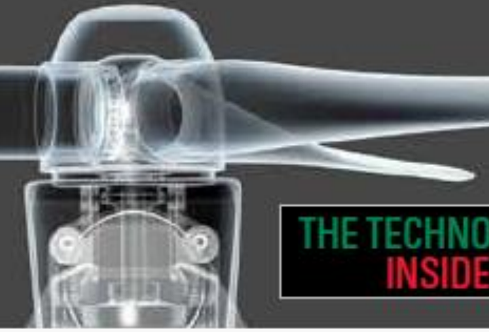
Improved Maintenance:

- Through increased monitoring using grease analysis and CMS
- Ensure proper regreasing frequency is followed

Lubricant based options to extend bearing life:

- Understand the unique operational challenges of main bearings
- Benchmark current product performance in use
- Identify lab tests to correlate to field challenges and performance
- Formulate based on grease thickening systems, base oils and additive interactions / synergies
- Higher technology grease with unique surface improving qualities to maximize bearing life

What's A Lubricating Grease ?



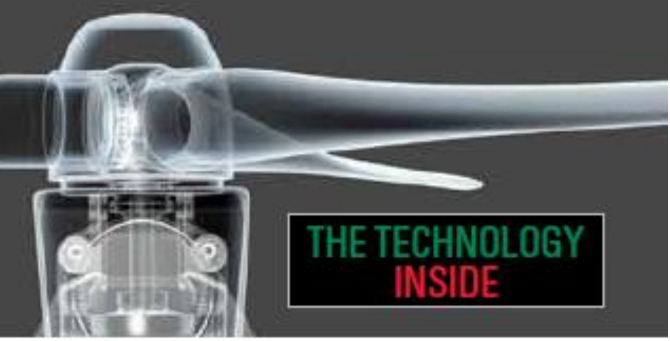
ASTM defines Grease as:

"a solid to semi-fluid product or dispersion of a thickening agent in a liquid lubricant. Other ingredients imparting special properties may also be included"

- **Base oil (60-80%):** performs the primary lubrication functions; kept within the thickener by a combination of Van der Waals and capillary forces.
- **Thickener (2-30%):** fibrous/gel-like material to hold base oils and additives
- **Additives (0 -10%):** liquid or solids to improve certain properties such as EP AW, Rust Inhibitors, VI improvers, tackiness/adhesion, etc.

Base Oils

- **Mineral Oils**:
  - Paraffinic, Group 1, 2 and 3
  - Naphthenic
- **Synthetic Oils**:
  - PAOs
  - Esters
  - PAGs
  - Silicone
  - PFPEs
- **Biobased oils**
  - Vegetable Oils
  - Vegetable Oils Derivatives



Complex Grease Thickening Systems

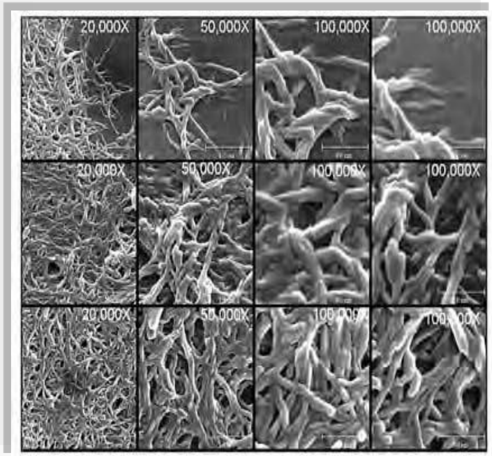
Lithium Complex, Calcium Complex

Lithium Complex is popular for high temperature applications:

- High dropping point (>300C)
- High continuous operating temperature:
  - **150ºC mineral based**
  - **200ºC synthetic based**
- Excellent **oxidation resistance**

Advantages in wind turbine applications:

- Excellent **mechanical stability**
- Excellent **oil separation properties**
- Acceptability of the additives
- Broad compatibility with other grease types



Micrograph (D): Lithium Complex Greases Using STRATCO® Contactor™ Reactor

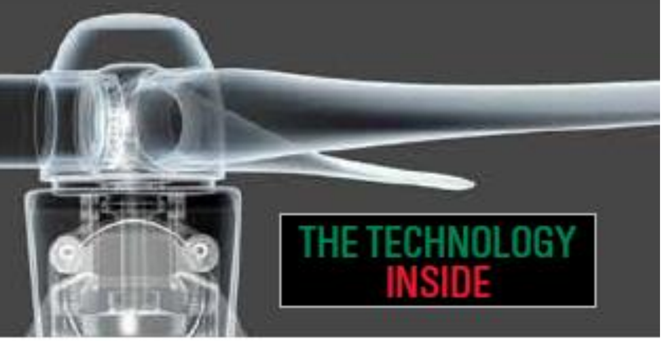
Complexing agents

1. Adipic acid
2. Sebacic acid
3. Azelaic acid

$$\underbrace{CH_3\text{-}(CH_2)_5\text{-}CHOH\text{-}(CH_2)_{10}\text{-}COOH}_{\text{12-hydroxy stearic acid}} + \underbrace{LiOH}_{\text{Lithium Hydroxide}} \longrightarrow \underbrace{CH_3\text{-}(CH_2)_5\text{-}CHOH\text{-}(CH_2)_{10}\text{-}COOLi}_{\text{Lithium 12-OH stearate soap}} + \underbrace{H_2O}_{\text{Steam}}$$

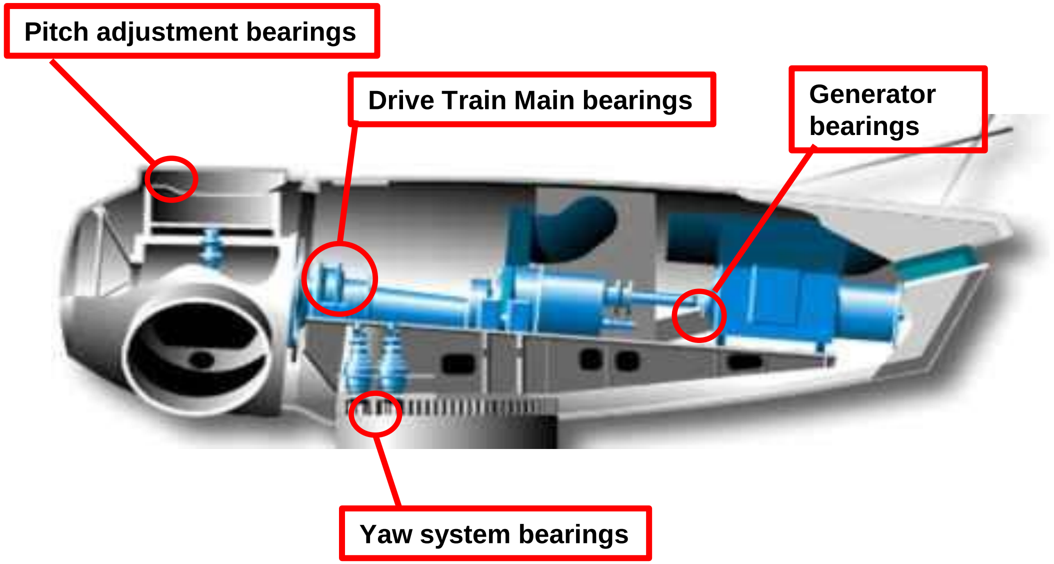
Common Additives for Greases

Additive	Purpose	Examples
Extreme Pressure (EP) & Anti-wear	Prevent metal to metal contact under extreme pressure and temperature	ZDTP, phosphates, sulfurized fats
Anti Oxidants	Slow the oxidation (breakdown) process	ZDTP, hindered phenols, amines
Friction Modifiers	Reduce friction and increase efficiency	MoDTC, MoDTP, phosphorous, esters
Rust Inhibitors	Slow corrosion reactions	Phenolates, sulfonates
VI Improvers	Improve viscosity performance at low and high temperatures	Polybutadienes, OCP, Polyisobutilenes, PMA
Pour Point Depressants	Improve flow at low temperatures	Diverse Polymers
Solid Friction Modifiers	Reduce friction and increase efficiency	MoS2, Graphite, CaCO3
Tackifiers	Resist water/chemical wash out	High MW polymers

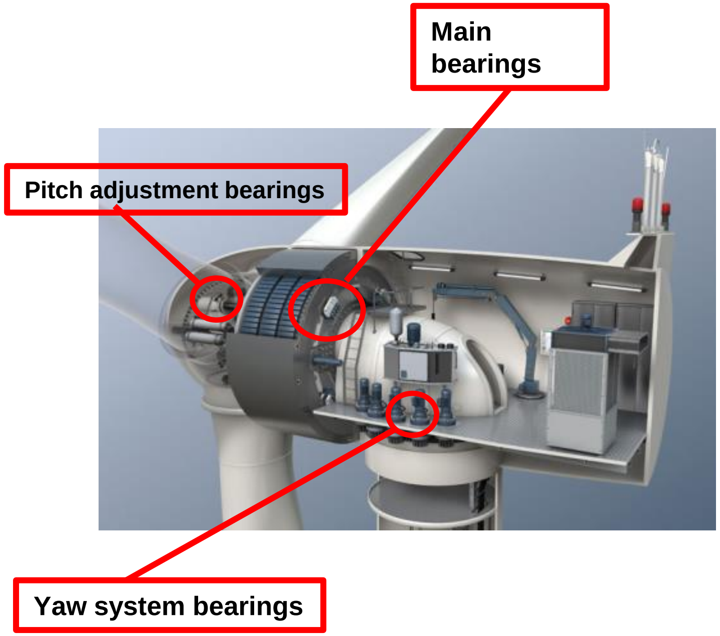


Wind Turbine Grease Applications

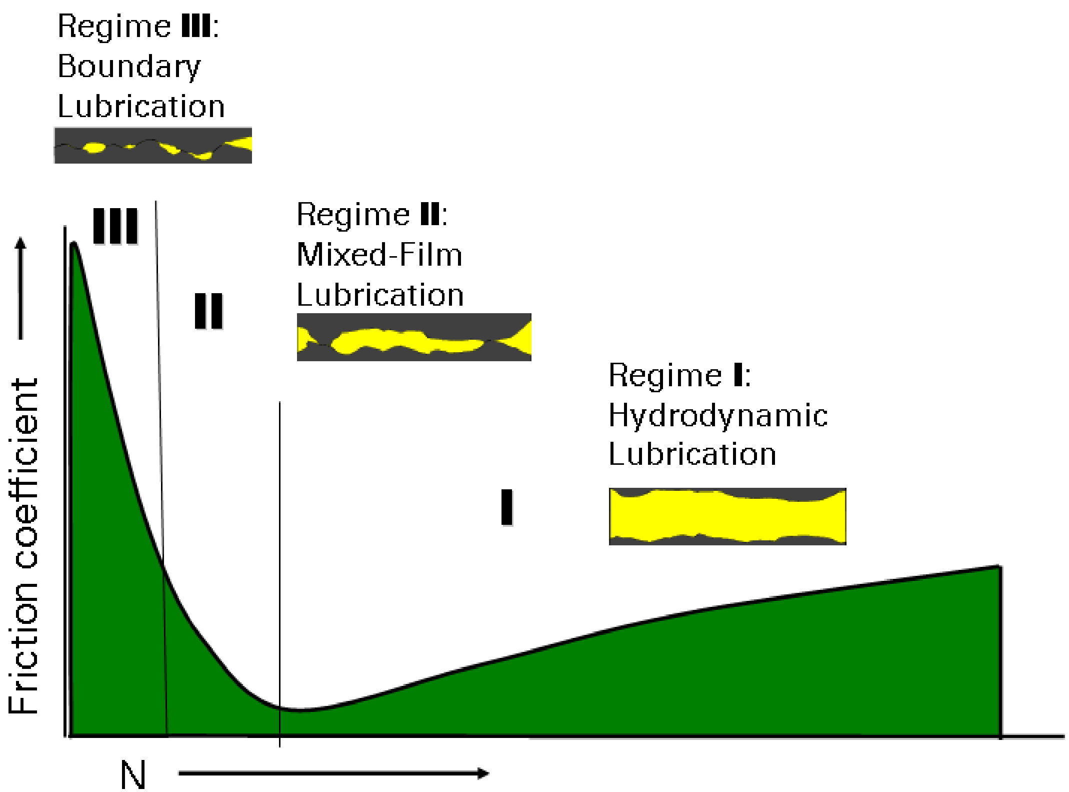
GEARBOX TYPE



DIRECT DRIVE



Stribeck curve

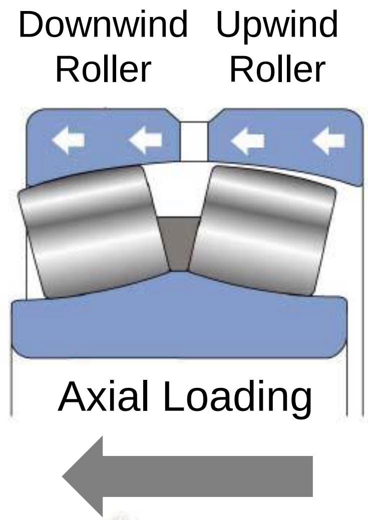


$$N = \text{Stribeck number} = 10^8 \times \frac{\text{viscosity} \times \text{speed}}{\text{load}}$$

- Boundary conditions are more common in the heavy duty industries due to low speeds, high loads and high temperatures.
- Primary function of lubrication is to supply a lubricating film preventing metal-to-metal contact <u>in all conditions.</u>

Main Bearing Greases

Formulating to Meet the Challenges



Wind Turbine Main Bearing Grease Product Profile

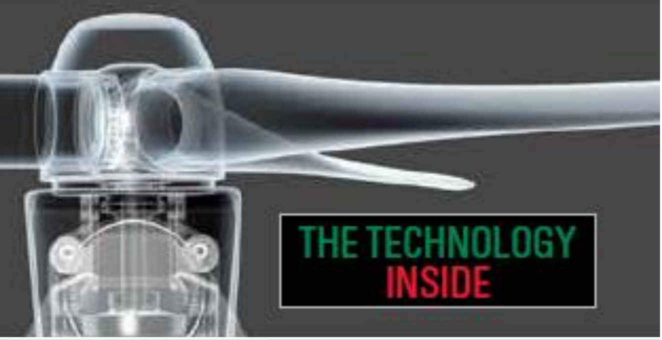
- Withstand high loads and shock loads (including axial loads)
- Resist service wear and fretting wear
- Display low friction for energy saving and long component service life
- Resists shearing (good mechanical stability)
- Resists water ingress
- Resists corrosion attack
- Good mobility at low temperatures (easy start up)
- Controlled bleed rate and oil separation

Challenge

- Multiple test protocols and specifications
- Combining all ideas for such a grease into just ONE product
- May not meet the needs of other WT applications (ie. pitch, yaw)
- Requirements continue to change based on WT design

Wind Turbine Bearing

Application Challenges



Operating Conditions / Challenges	Grease Requirements	Potential Bench Tests to Indicate Performance
Stop/Start and low speed	Wear protection, film thickness Low friction - energy efficiency	FE8, SRV
Stand-still conditions and vibration	Resistance against fretting and fretting corrosion	Ripple IME, SNR FEB2, Fafnir, SRV
Rapidly changing loads	Load carrying/EP capability Low friction - energy efficiency	FE8, SRV, 4-Ball EP
High thrust load/movement (main shaft bearing)	Wear protection Low friction - energy efficiency	FE8, SRV
Water contamination (Condensation or environment /sea water)	Water resistance Corrosion protection (sea water)	Ripple with water and salt water, Emcor Rust Test
Very long re-lubrication intervals	Long term shear stability	Worked Stability, Roll stability
Low start up temperatures Low temperature application	Low temperature start-up and running torque Low temperature pumpability	Low temp torque, Flow pressure

Benchmark Program

Commercially Available Products

Product	COM A	COM B	COM C	COM D	COM E	COM F
NLGI grade	1	1	1.5	2	1.5	1
WP [mm/10]	330	340	305	302	305	315
Base Oil Type	Syn/M	Syn/M	Syn	Syn	Syn	M
Base Oil ISO Grade	150	320	460	320	460	1000
Thickener type	LiCpx	LiCpx	LiCpx	Li-12-OH	LiCpx	Li-12-OH
Application (PDS)	M/P/Y	-	M/P/Y	M/P/Y	-	-

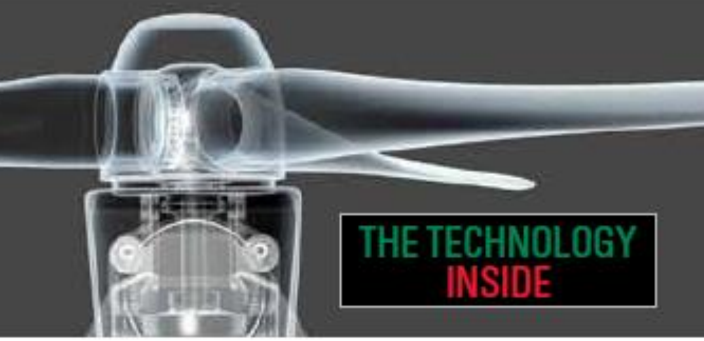
	COM A	COM B	COM C	COM D	COM E	COM F
Mechanical Stability	medium	good	poor	poor	good	good
Corrosion	medium	medium	good	good	good	poor
Low Temp Property	good	poor	poor	good	medium	poor
FE8 - Wear	good	good	medium	good	good	medium
FE8 – Temp /Torque	poor	good	medium	good	good	medium
Ripple Test - IME	good	medium	poor	medium	good	good
Ripple Osc Test no NaCl	good	good	medium	medium	medium	good
Ripple Osc Test with NaCl	poor	medium	good	good	medium	medium
SNR FEB2 Test	good	good	poor	poor	poor	medium
FAFNIR - ASTM D4170	medium	good	poor	poor	poor	good
SRV - ASTM D7594	good	medium	medium	poor	poor	good
SRV - ASTM D7594 @ 0°C	good	poor	good	poor	poor	poor

Relative Performance Rating		
good	medium	poor

Benchmark Evaluation / Conclusions

- All the products tested had different characteristics for similar applications
  - Base Oils: Mineral, Synthetic, or Combinations
  - Base Oils ISO Grades: ISO 150, 320, 460 and 1000
  - Thickening systems: Lithium 12-OH and Lithium Complex
  - NLGI grades: 1, 1.5 and 2
- Performances in the identified lab tests (SRV, FE-8, etc.) varied widely
- Fretting Wear Tests: Correlations to field performance
- Development of a new grease candidate:
  - Starting with the thickening system
  - Additive interaction
  - Process optimization
  - Product testing and validation

Benchmark Program
Developing Grease Candidates



Product	COM A	COM B	COM E	COM F	CAN 1	CAN 2
NLGI grade	1	1	1.5	1	1.5	1
WP [mm/10]	330	340	305	315	300	325
Base Oil Type	Syn/M	Syn/M	Syn	M	Syn/M	Syn/M
Base Oil ISO Grade	150	320	460	1000	320	320
Thickener type	LiCpx	LiCpx	LiCpx	Li-12-OH	Li-12-OH	Li-12-OH
Application (PDS)	M/P/Y	-	-	-	M/P/Y	M/P/Y

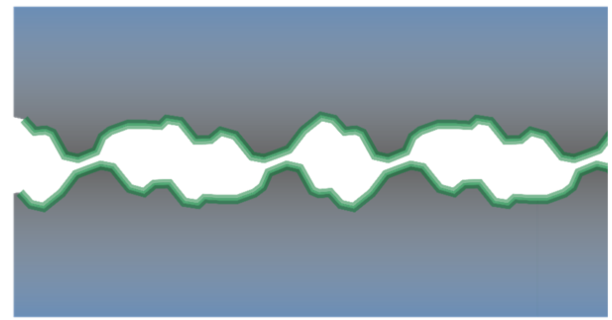
	COM A	COM B	COM E	COM F	CAN 1	CAN 2
Mechanical Stability	medium	good	good	good	medium	medium
Corrosion	medium	medium	good	poor	good	good
Low Temp Property	good	poor	medium	poor	good	good
FE8 - Wear	good	good	good	medium	good	good
FE8 – Temp /Torque	poor	good	good	medium	medium	medium
Ripple Test - IME	good	medium	good	good	medium	medium
Ripple Osc Test no NaCl	good	good	medium	good	good	good
Ripple Osc Test with NaCl	poor	medium	medium	medium	medium	medium
SNR FEB2 Test	good	good	poor	medium	poor	medium
FAFNIR - ASTM D4170	medium	good	poor	good	good	good
SRV - ASTM D7594	good	medium	poor	good	good	good
SRV - ASTM D7594 @ 0°C	good	poor	poor	poor	poor	medium

Relative Performance Rating		
good	medium	poor

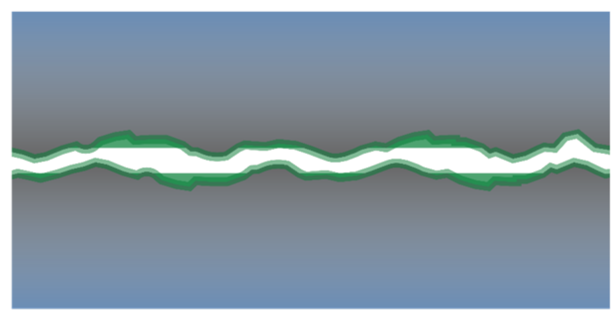
WEAR PROTECTION, LONG-LASTING APPROACH:
MICROFLUX TRANS PLASTIC DEFORMATION TECHNOLOGY*

THE TECHNOLOGY INSIDE

FROM SACRIFICIAL PROTECTION…



…TO SURFACE MICROSMOOTHING



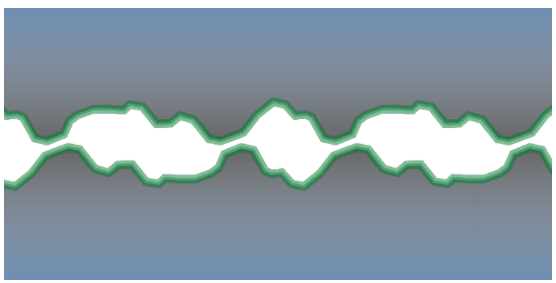
*MFT-PD Technology = TGOA Technology

MICROFLUX TRANS

PD TECHNOLOGY

STAGE
1

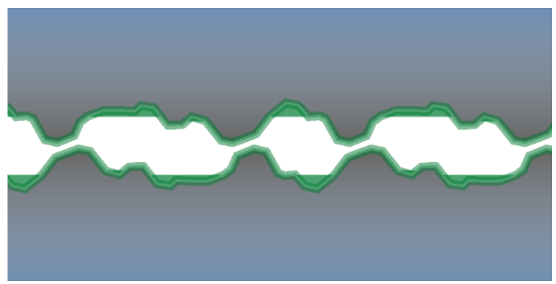
PROTECTION



PROTECTIVE LAYER FORMS IMMEDIATELY

STAGE
2

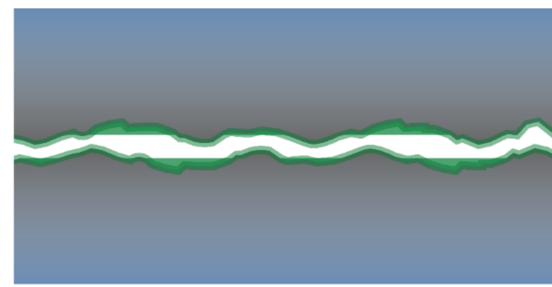
COMPRESSION



PROTECTIVE LAYER COMPRESSED, REDUCING FRICTION

STAGE
3

MICROSMOOTHING



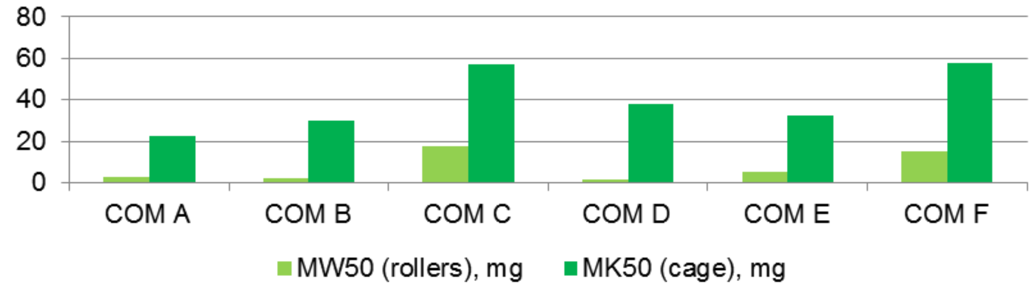
ADDITIVES MIGRATE INTO METAL SURFACE

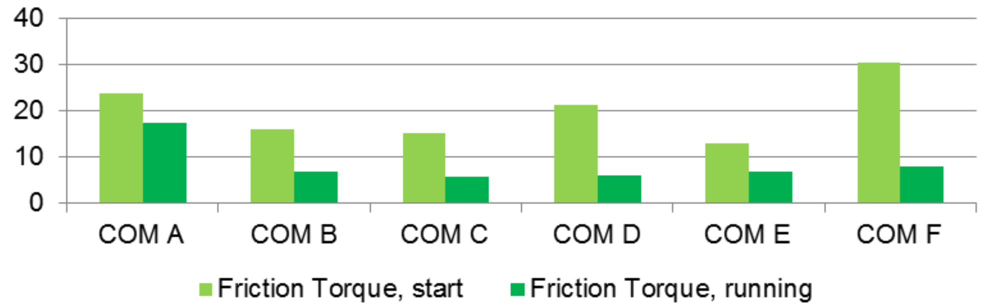
Wear Protection – FE8 Test

THE TECHNOLOGY INSIDE

FE8 TEST - DIN 51819-2: Mechanical-dynamic testing in roller bearing test apparatus FE8

- Fill two tapered roller bearing (31312) with 200 mL grease/ bearing
- Mount on roller bearing test apparatus
- Temperature = RT, no cooling
- Duration = 500 h
- Speed = 75 rpm
- Axial load = 50 kN





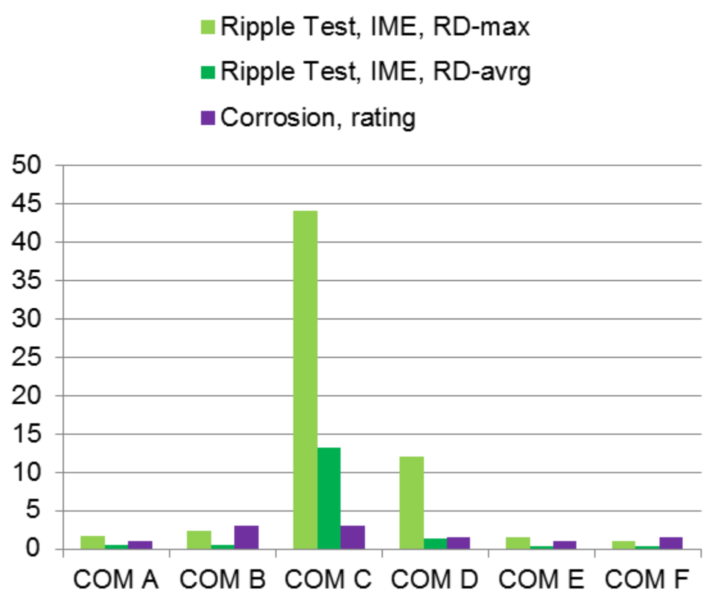
Property	COM A	COM C	COM E	CAN 3
MW50 [mg]	2.9	17.6	2.4	3.5
MK50 [mg]	22.5	57.1	30.1	9.0
Torque -Start [Nm]	24.1	15.3	17.7	11.4
Torque -Running [Nm]	17.6	5.7	7.2	5.7
Temp - max [°C]	106	57	87	46
Temp -Running [°C]	88	52	58	46

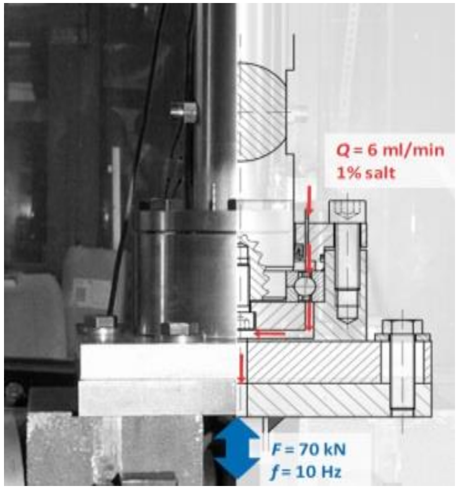
Ripple & Corrosion Protection

IME Aachen

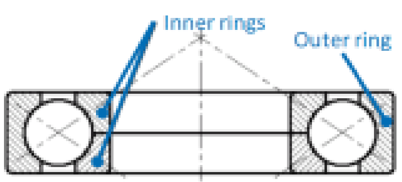
THE TECHNOLOGY INSIDE

Bearing: **Four point cantact ball bearing**
(FAG QJ212.TVP)
Load: **70 kN**
Test duration: **28 h (1 mio cycles)**
Frequency: **10 Hz**
Contamination: **1% NaCl at 6ml/min**
Measurement: **maximum ripple depth, Average ripple depth, corrosion grade**
Limits: **RD-max ≤ 10 µm** | **RD-av ≤ 3 µm, Corrosion grade ≤ 2**

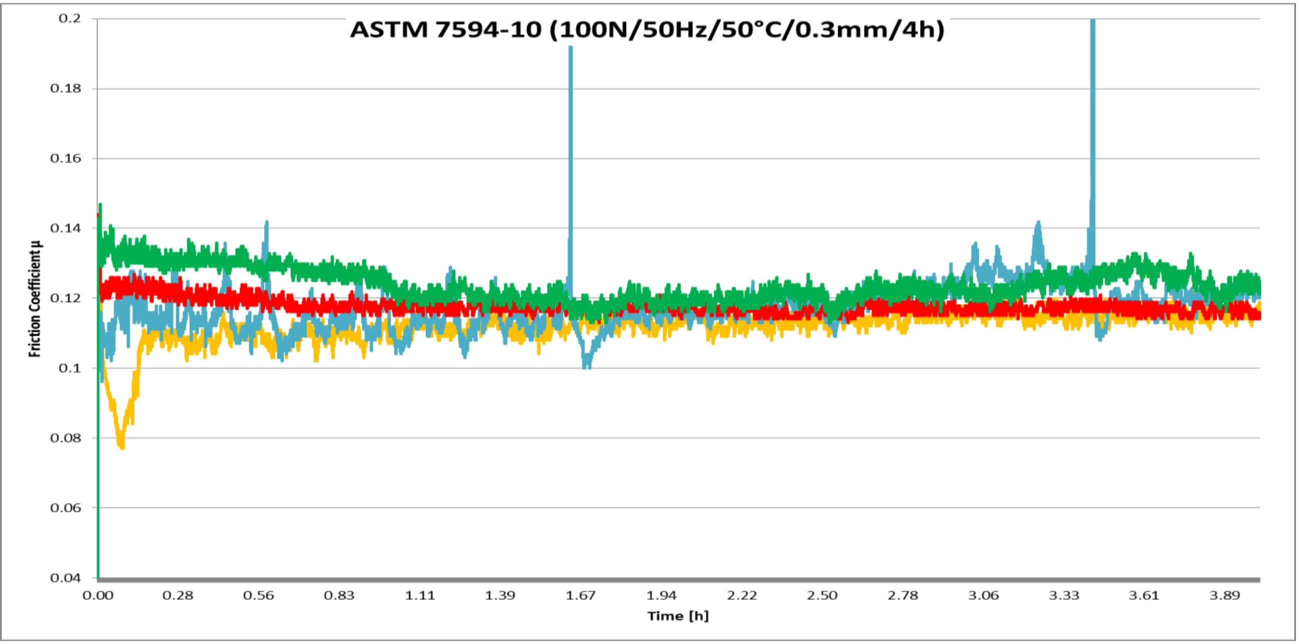


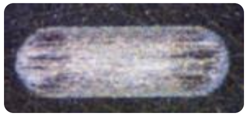


Product	COM A	COM B	COM C	CAN 3
Ripple Depth – Max [µm]	1.7	2.3	44.1	2.6
Ripple Depth – Av [µm]	0.45	0.60	13.2	0.6
Corrosion Grade	1.0	3.0	3.0	1.0

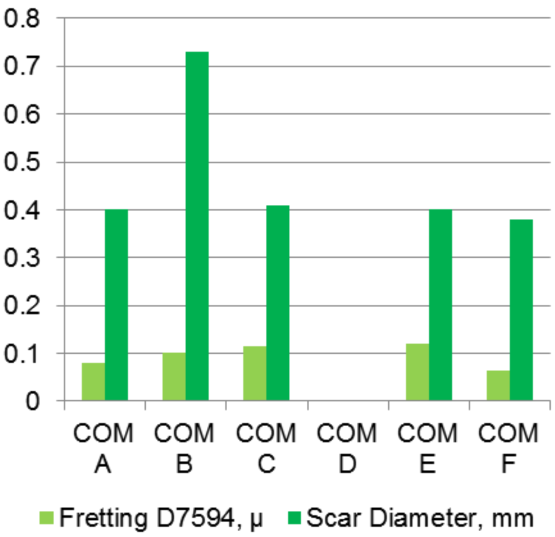


SRV – Fretting Test ASTM 7594
(100N | 50Hz | 50°C | 0.3mm | 4h)



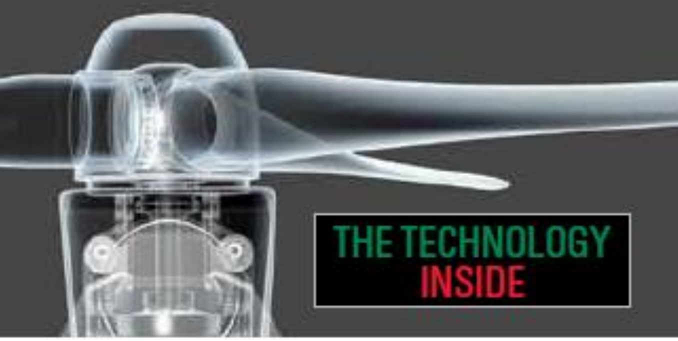


ASTM 7594 at 50°C	COM A	COM B	COM C	CAN 3
Ball Scar Diameter, mm	0.40	0.73	0.41	0.33



Benchmark Program

Produce Trial Batch – Process Verification



Product	COM A	COM B	COM E	COM F	CAN 1	CAN 2	CAN 3	CAN 3 Trial batch
NLGI grade	1	1	1.5	1	1.5	1	1	1
WP [mm/10]	330	340	305	315	300	325	330	340
Base Oil Type	Syn/M	Syn/M	Syn	M	Syn/M	Syn/M	Syn	Syn
Base Oil ISO Grade	150	320	460	1000	320	320	460	460
Thickener type	LiCpx	LiCpx	LiCpx	Li-12-OH	Li-12-OH	Li-12-OH	LiCpx	LiCpx
Application (PDS)	M/P/Y	-	-	-	M/P/Y	M/P/Y	M/P/Y	M/P/Y
Mechanical Stability	medium	good	good	good	medium	medium	good	good
Corrosion	medium	medium	good	poor	good	good	good	good
Low Temp Property	good	poor	medium	poor	good	good	good	good
FE8 - Wear	good	good	good	medium	good	good	good	good
FE8 – Temp /Torque	poor	good	good	medium	medium	medium	good	good
Ripple Test - IME	good	medium	good	good	medium	medium	good	good
Ripple Osc Test no NaCl	good	good	medium	good	good	good	good	good
Ripple Osc Test with NaCl	poor	medium	medium	medium	medium	medium	good	good
SNR FEB2 Test	good	good	poor	medium	poor	medium	good	good
FAFNIR - ASTM D4170	medium	good	poor	good	good	good	good	good
SRV - ASTM D7594	good	medium	poor	good	good	good	good	good
SRV - ASTM D7594 @ 0°C	good	poor	poor	poor	poor	medium	good	good

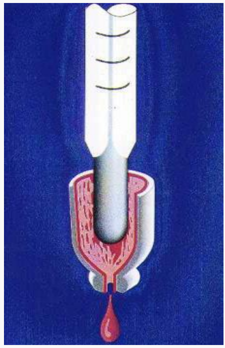
Relative Performance Rating		
good	medium	poor

Field Testing and Validation

- Trial preparation
  - Compatibility testing
  - Cleaning and flushing old grease
- Baseline data
  - Old grease analysis
  - Inspection photos
  - Temperature, vibration, and other data
- Trial data
  - Duration
  - Grease analysis
  - Inspection photos
  - Temperature, vibration and other data

Grease Compatibility

ASTM D 6185 Compatibility of Binary Lubricating Greases



PRIMARY COMPATIBILITY TESTING:

Option 1: Greases A and B and 50:50 mixture.

- Run DP, 100 K and HT Storage Stability.
- If all tests pass, make 10:90 and 90:10 mixtures and run same tests.
- If all tests pass, greases A & B are compatible per the primary criteria

Option 2: Greases A and B, 10:90, 50:50 and 90:10 mixtures.

- Run DP, 100 K and HT Storage Stability.
- If all the mixtures pass the 3 tests, Greases A and B are compatible as per the primary criteria

SECONDARY COMPATIBILITY TESTING

If additional testing is required depending on the criticality of the specification requirements, selection should be made from a list of the secondary tests (for example: Oil Separation, Four Ball EP, Four Ball Wear, Rust, Copper Corrosion, Fretting Wear, Water Washout, etc...)

Summary: Improved Grease Performance Yields Longer Bearing Life

Keys to making those improvements:

- Understand the unique operational challenges of wind turbines
- Benchmark current product performance in use
- Identify lab tests to correlate to field challenges and performance
- Formulate based on grease thickening systems, base oils, and additive interactions / synergies
- Optimize manufacturing process for better product performances
- Field testing and validation

- Ultimately the grease needs the identified key attributes for assuring adequate lubrication and long service life of wind turbine bearings

Wind Turbine Grease Summary
Main and Yaw Bearings

THE TECHNOLOGY INSIDE

Grease designed to meet these requirements

- ✓ High shear stability for long life functionality
- ✓ Excellent bearing wear protection
- ✓ High load carrying capability
- ✓ Excellent low temperature start-up and running torque
- ✓ High water resistance
- ✓ Very good corrosion resistance (sea water)
- ✓ Good pumpability at low temperatures
- ✓ Excellent friction properties - energy efficiency
- ✓ Good Fretting/False Brinelling protection per SRV testing

CHANGEOVER PROCEDURE (GREASE)

TURBINE:
GE 1.X MW

MAIN BEARING CONFIGURATION

- SKF and Schaeffler FAG bearings
- Manual lubrication, no auto-lube system
- Lube cycle every 6 months using 2+ standard 14 oz. / 400 cc tubes
- The bearing capacity is about 30 lbs. of grease. Two 5-gallon pails are recommended to perform an effective purging of the bearing and to fill the reservoir

LOCK RING

MAIN BEARING

INSPECTION COVER PULLED

CHANGEOVER PROCEDURE

- Remove lock ring, bolts for inspection cover and pull back cover
- If used, clean pail pump and follower plate. Install the new grease 5-gallon pail. Operate the pump until all old grease is purged from the outlet hose to waste.
- Remove old grease manually from in between rollers and take a used grease sample from between the rollers. Reinstall cover and lock ring.
- Operate the lube pump to fill and purge the bearing housing through the seals and bottom purge plug.
- After a while, a mixture of greases will be seen purging.
- Expect a total of around 20 lbs. of grease to be pumped into the bearing.
- Set the turbine to pinwheel at low rpm (1 – 2 rpm) .
- Continue to pinwheel about 20 minutes until all grease has purged from the inspection ports. Around 12 lbs. should be purged.
- Pump the remaining new grease into the bearing through the button head grease fitting.
- Re-assemble all equipment, and clean and inspect the area.
- Put the turbine back into operation.

BOTTOM PURGE PORT

PURGING FROM SEALS

ALTERNATIVE PROCEDURE: Romax Insight has a hot oil grease flushing procedure that can remove up to 90 % of used grease and iron particulate. Can be used when higher cleanliness is desired and incompatible greases are involved.

GREASE PERFORMANCE METRICS

VISUAL Borescope every 3 months to look for smoothing or verify no damage has been caused by grease incompatibility or inadequate lubrication. Use the proper procedure, with pictures labeled with location.

TEMPERATURE Ensure no main shaft bearing temperature alarms are triggered and trends do not begin to differ significantly from neighboring turbines.

VIBRATION

Compare vibration trends to historical data.

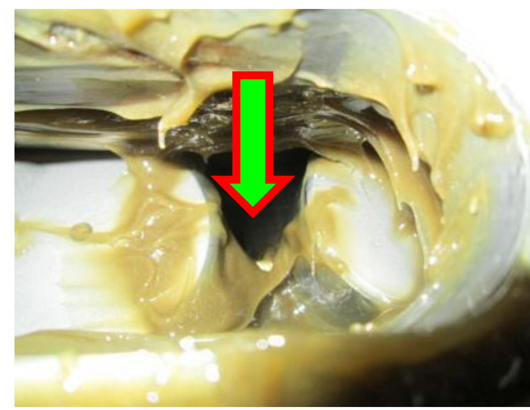
GREASE SAMPLING

Compare iron (Fe) trends.

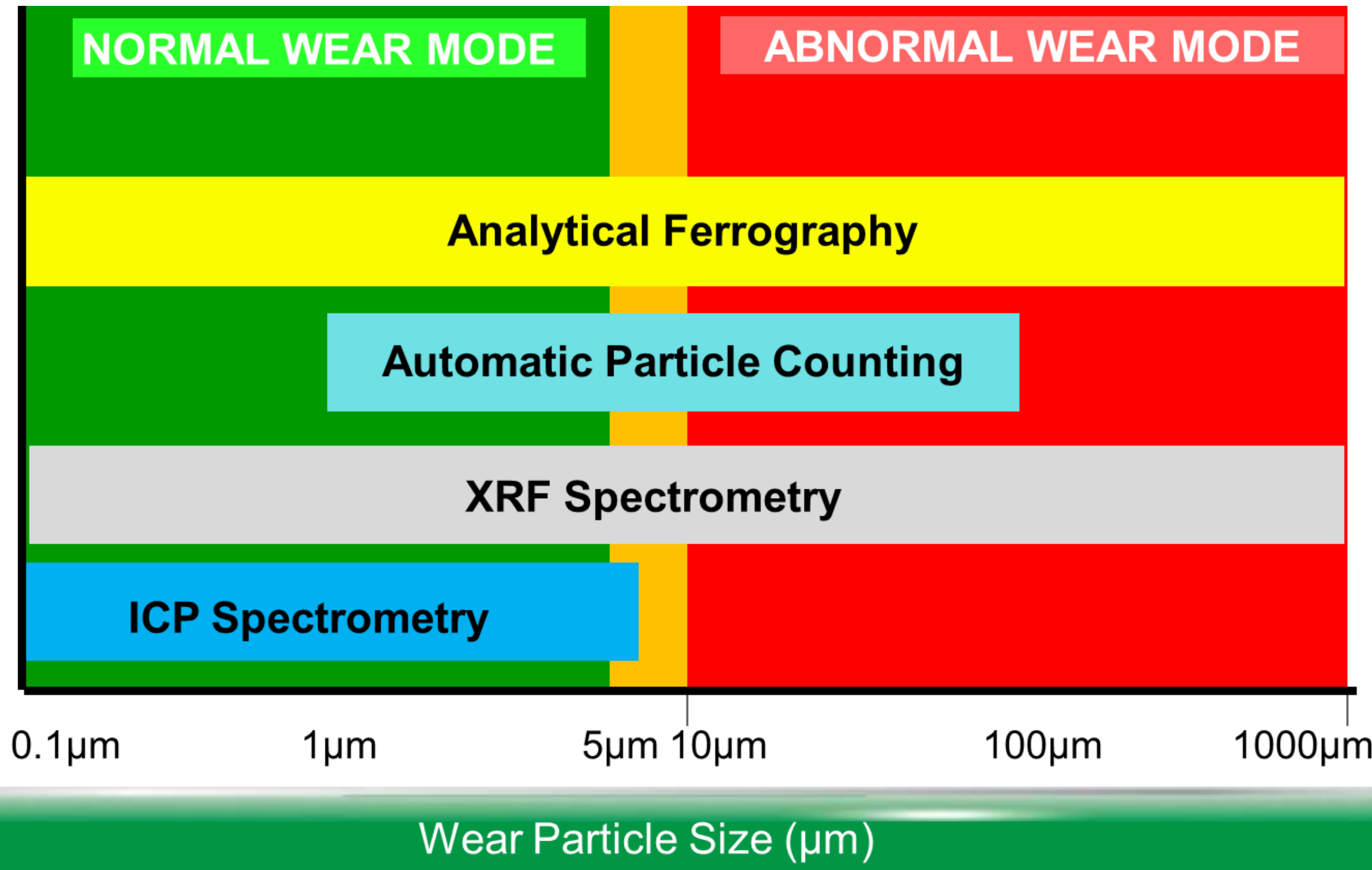
Monitor Main Bearing Grease

Used Grease Analysis – What Is Important

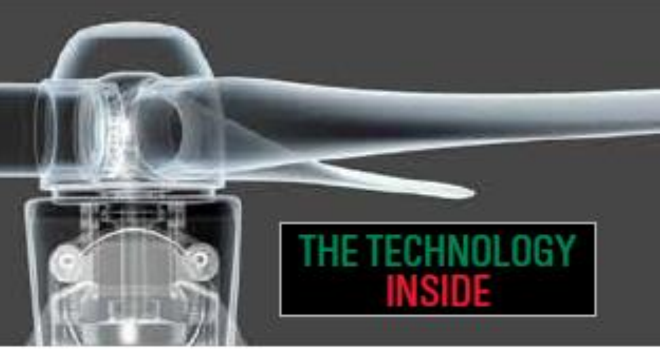
- Correct Grease Sampling
  - Remove grease immediately inside port with clean rag or spatula.
  - Sample grease from between rollers with clean spatula or using your finger with a nitrile glove.
  - Use a Grease Thief



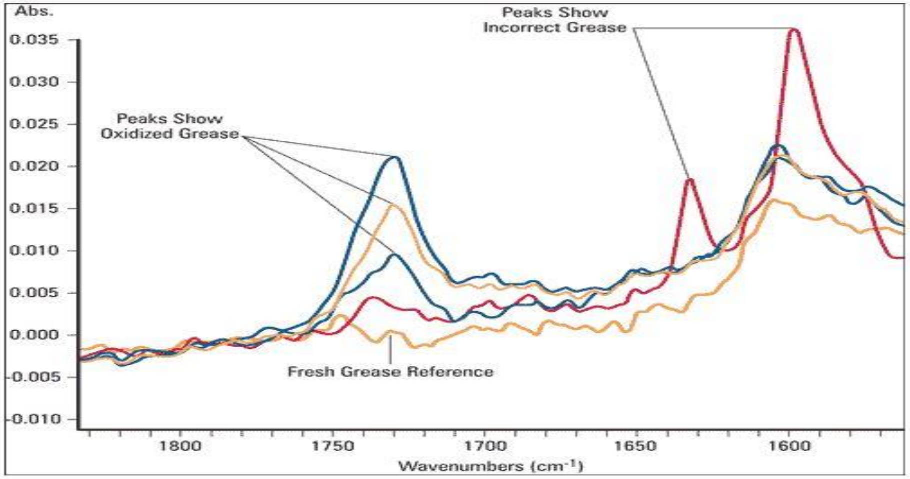
Particle Detection

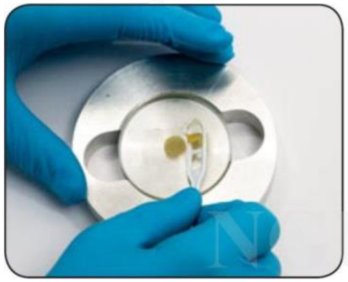


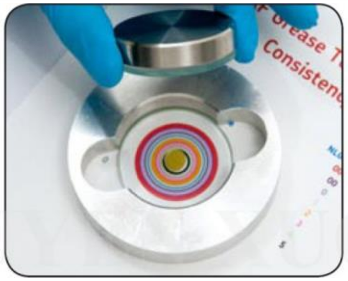
Grease Analysis

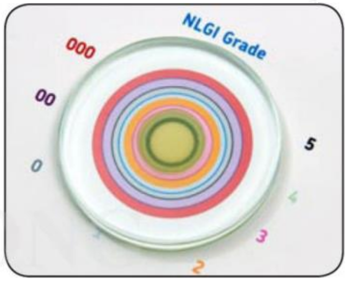


- **Only 5 g sample is required**
  - **Visual / colour**
  - **Water content**
  - **Acid Number**
  - **PQ wear index**
  - **XRF spectrometry**
- **Additional testing could include**
  - **FT-IR spectrometry**
  - **Analytical ferrography**
  - **Oil bleeding**
  - **NLGI class**

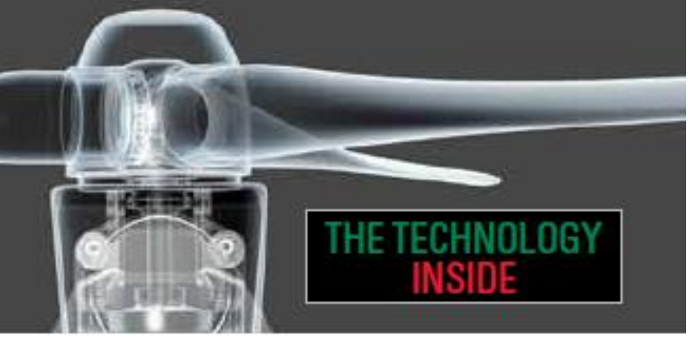








Grease Analysis Report

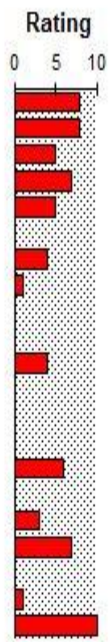


Test Name	Method	Unit	Results				
			GD4039	GD5141	GD7944	GD8915	GD12305
PHYSICAL-CHEMICAL ANALYSIS							
Colour	ASTM-D1500	-	6.0	6.0	6.0	6.0	**6.5**
Visual appearance	OMS 13882	-	smooth	smooth	smooth	smooth	**smooth**
Water (KF)	ASTM-D6304	ppm	474	248	932	731	**773**
Neutralisation Value (NV)	ASTM-D974	mg KOH/g	2.68	2.70	2.90	3.30	**3.06**
PQ - Wear index	OMS 14406	-	84	84	92	68	**91**
ELEMENTAL ANALYSIS							
Magnesium XRF	ASTM-D7751	ppm	102	94	23	25	**< 51**
Aluminium XRF	ASTM-D7751	ppm	< 10	25	< 10	< 10	**< 10**
Silicon XRF	ASTM-D7751	ppm	4	18	< 3	5	**< 3**
Phosphorus XRF	ASTM-D7751	ppm	1646	1723	1906	2013	**2213**
Sulphur XRF	ASTM-D7751	ppm	9548	9930	10310	10790	**11070**
Chlorine XRF	ASTM-D7751	ppm	9	18	18	16	**25**
Potassium XRF	ASTM-D7751	ppm	2	3	3	1	**< 1**
Calcium XRF	ASTM-D7751	ppm	1237	1294	1840	1808	**1744**
Titanium XRF	ASTM-D7751	ppm	< 1	< 1	< 1	< 1	**1**
Vanadium XRF	ASTM-D7751	ppm	< 1	< 1	< 1	< 1	**< 1**
Chromium XRF	ASTM-D7751	ppm	< 1	2	0	< 1	**< 1**
Manganese XRF	ASTM-D7751	ppm	3	3	2	2	**2**
Iron XRF	ASTM-D7751	ppm	98	195	94	93	**98**
Cobalt XRF	ASTM-D7751	ppm	< 3	< 3	< 3	< 1	**< 3**
Nickel XRF	ASTM-D7751	ppm	3	4	4	5	**3**
Copper XRF	ASTM-D7751	ppm	13	14	9	8	**6**
Zinc XRF	ASTM-D7751	ppm	2276	2444	2511	2592	**2681**
Molybdenum XRF	ASTM-D7751	ppm	< 1	1	1	< 1	**1**
Tin XRF	ASTM-D7751	ppm	< 5	< 5	0	< 5	**< 5**
Antimony (Sb)	ASTM-D7751	ppm	< 5	< 5	< 5	3	**< 5**
Barium XRF	ASTM-D7751	ppm	3	6	4	< 1	**1**
Lead XRF	ASTM-D7751	ppm	< 1	1	0	< 1	**< 1**

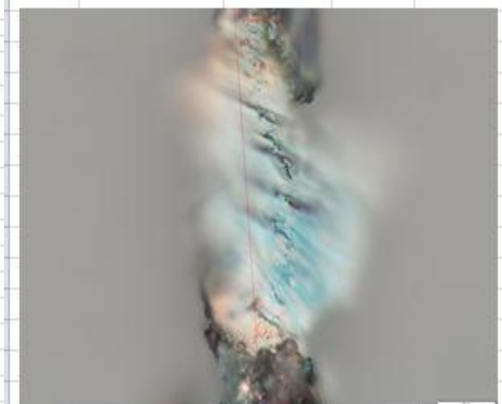
Report

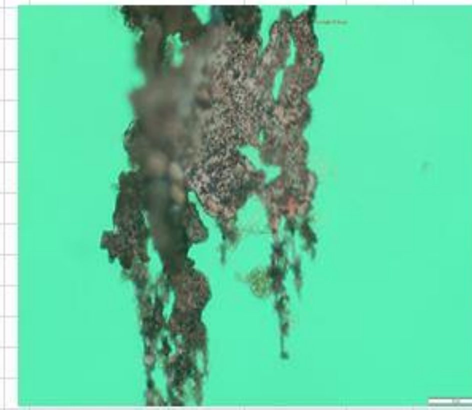
PQ Wear Index	148

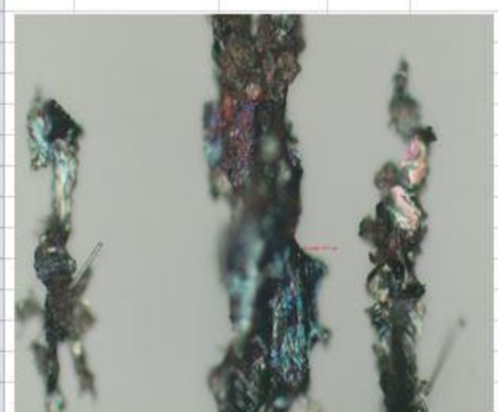
PARTICLE TYPE	Size, µm
FERROUS	
Normal Rubbing	<15
Severe Sliding	170
Cutting	50
Chunks	110
Flakes	75
Spheres	
Black Oxides	
Red Oxides	
Corrosives	
NONFERROUS	
Normal Rubbing	<15
Severe Sliding	
Cutting	
Chunks	
Flakes	80
CONTAMINANTS	
Lube Degradation	
Sand/Dirt	
Contaminant Fibres	
Contaminant Spheres	15
Others	

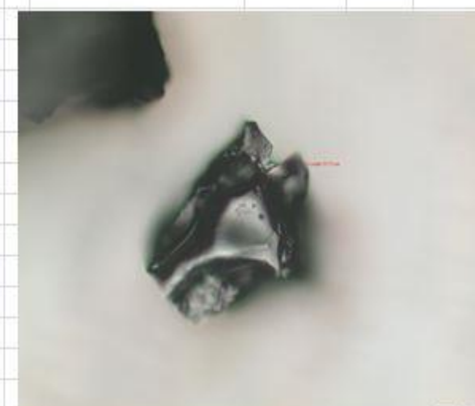


XRF Spectrometry (ppm)	
Aluminium (Al)	21
Chromium (Cr)	2
Copper (Cu)	22
Iron (Fe)	397
Nickel (Ni)	7
Lead (Pb)	161
Silicon (Si)	251
Tin (Sn)	26
Sulphur (S)	1833
Potassium (K)	21
Calcium (Ca)	119
Zinc (Zn)	802
Barium (Ba)	179


Low alloy steel severe sliding wear particle


Bearing flake (70 µm)


Case hardened fatigue chunk


Carbonised contaminant

Thank you!