Overview

- Wind Turbine Gear boxes
  - Challenges and Lubrication Impact

- Lubricant Formulation Approaches
  - Balanced Performance
  - Key Performance Parameters

- Next Generation Wind Turbines
Gear Box Lubrication Challenges
WT Gearbox Lubrication Challenges

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<th>Key Lubricant Formulation Parameter</th>
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<td>Weight restrictions on gear box:</td>
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<td>Micropitting Protection</td>
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<td>• compact design;</td>
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<td>Gear and Bearing Protection</td>
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<td>• high load handling capability;</td>
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<td>Oxidative Stability</td>
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<td>• case hardening of gears</td>
<td>Creates environment susceptible to micropitting and wear</td>
<td>Viscometrics</td>
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<td>Demand for extended oil drain intervals</td>
<td>Demands oil performance retention over time</td>
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<td>Use of fine filtration</td>
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<td>Off-shore wind turbines</td>
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<td>Changing ambient temperatures and non-permanent operation</td>
<td>Requires stable operation of lubricant in wide ambient temperature range</td>
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Lubrication Approaches
Balanced Formulation Approach

Common Approach

Baseoil + Off-the-Shelf Additive Package → Lubricant Product with reasonable performance

Step Out Formulation Approach

Balanced Additive System + Optimal Base Stocks + Many years of experience in formulation and application → Major investment in extensive testing using industry standard glassware, proprietary rig, and field tests

Scientifically Engineered High Performance Synthetic Oils
Balanced Formulation Approach

Key Lubricant Formulation Parameters

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| Oxidative Stability |
| Viscometrics |
| Foam and Air Release |

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| Water Tolerance |
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| Low Temp Performance |

Next Generation Synthetic WT Gear Oil
Current Synthetic WT Gear Oil
# Balanced Formulation Approach

## Key Lubricant Formulation Parameters

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[Diagram showing performance metrics for different lubricants]
Balanced Formulation – Customer Value

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<tr>
<th>Key Lubricant Formulation Parameter</th>
<th>Equipment protection</th>
<th>Wear protection for equipment</th>
<th>Long oil life</th>
<th>Long filter life</th>
<th>Stable viscosity at high and low temperatures</th>
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<tr>
<td>Micropitting Protection</td>
<td>Reduced downtime for maintenance</td>
<td>Reduced downtime for maintenance</td>
<td></td>
<td></td>
<td>Protection at low temperature start up</td>
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<tr>
<td>Gear and Bearing Protection</td>
<td>Improved wear performance</td>
<td>Reduced maintenance</td>
<td></td>
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<tr>
<td>Oxidative Stability</td>
<td>Reduced foaming and oil sump retention times</td>
<td>Consistent performance upon water ingress</td>
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</tr>
<tr>
<td>Viscometrics</td>
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</tr>
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- Next Generation Synthetic WT Gear Oil
- Current Synthetic WT Gear Oil
- Synthetic WT Gear Oil

- Equipment protection
- Wear protection for equipment
- Long oil life
- Long filter life
- Stable viscosity at high and low temperatures

- Improved wear performance
- Reduced maintenance
- Reduced foaming and oil sump retention times
- Consistent performance upon water ingress
- Long filter life
- Reduced downtime for maintenance
- Reduced downtime for maintenance
- Protection at low temperature start up
Micropitting Protection at 60°C

- FVA 54 Test at 60°C
- Load Stage Result: > 10
- Endurance Test Result: GFT=high

Micropitted area GF of the test pinion

Average profile deviation of the test pinion

Weight loss of the test pinion

Lubricant should provide excellent resistance to formation of micropitting and retention of micropitting protection over time
Micropitting Protection at 90°C

- FVA 54 Test at 90°C
  - Load Stage Result: > 10
  - Endurance Test Result: GFT=high

Micropitted area GF of the test pinion

Average profile deviation of the test pinion

Weight loss of the test pinion

Lubricant should provide excellent resistance to formation of micropitting and retention of micropitting protection over time
Gear Scuffing Protection

• Gear protection from wear and scuffing is critical to long equipment life

• Gear Protection performance was evaluated based on the results of
  • FZG Scuffing Test (ISO 14635-1 mod)
    • Measures scuffing resistance and anti-wear performance under increasing loads using a standardized gear set. Modified from standard method to exceed load stage 12.
    • Single speed: A / 8.3 / 90
    • Double speed: A / 16.6 / 90

Example of scuffing on gear tested in FZG test stand

FLS >14
FLS >14
Gear and Bearing Protection

- Gear and bearing protection from scuffing and wear are critical to long equipment life

- Evaluated based on the results of:
  - FZG Scuffing Test (ISO 14635-1 mod)
    - Measures scuffing resistance and anti-wear performance using a standardized gear set
    - Single speed: A / 8.3 / 90 Result: FLS >14
    - Double speed: A / 16.6 / 90 Result: FLS >14

- FAG FE8 4-Stage Test for Wind Turbine Gear Oils
  - Measures lubricant performance in a bearing under varying load, speed, and temperature conditions.
  - Result: 1.0 (Scale = 1 to 5, 1 being highest)
## Bearing Protection: FAG 4-Stage Test

<table>
<thead>
<tr>
<th>Stage</th>
<th>Test Parameter</th>
<th>Friction Regime</th>
<th>Bearing Type</th>
<th>Test Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Wear</td>
<td>High Load / Low Speed (Extreme Mixed Friction)</td>
<td>FE8 Cylindrical Roller Thrust Bearing</td>
<td>100 kN 7.5 rpm 80°C, 80 h</td>
</tr>
<tr>
<td>2</td>
<td>Fatigue</td>
<td>Moderate Mixed Friction</td>
<td>FE8 Cylindrical Roller Thrust Bearing</td>
<td>90 kN 75 rpm 70°C, 800 h</td>
</tr>
<tr>
<td>3</td>
<td>Fatigue</td>
<td>EHL</td>
<td>L11 Ten Deep Groove Ball Bearing</td>
<td>8.5 kN 9000 rpm 85°C, 700 h</td>
</tr>
<tr>
<td>4</td>
<td>Deposit Formation</td>
<td>Mixed</td>
<td>FE8 Cylindrical Roller Thrust Bearing</td>
<td>60 kN 750 rpm 100°C, 600 h</td>
</tr>
</tbody>
</table>

Excellent performance in this test ensures robust bearing protection up tower, leading to improved equipment reliability and reduced downtime for maintenance.
Oxidative Stability

• Evaluated based on results of:
  • US Steel Oxidation Test (ASTM D2893*: 150°C, 312 h)
    • Test oil is heated to specified temperature in the presence of air.

Oxidative stability is a key factor in achieving extended oil life and oil drain intervals

% Change in KV @ 100°C

Acid Number Increase (mgKOH/g)

Better

* ASTM D2893 Modified in accordance with ISO 12925-1:1996 CKT specification
Viscometrics & Low Temp Properties

- Evaluated based on results of:
  - Viscosity Index (ASTM D2270)
  - Brookfield Viscosity (ASTM D2983)
    - Measures the apparent viscosity of oils at low temperatures
  - Pour Point (ASTM D 5950)
    - Lowest temperature at which sample moves when container is tilted

**Brookfield Viscosity @ -29°C (cP)**

- **Better**

**Viscosity Index**

- **Better**

Excellent low temperature properties protects equipment start up in extreme conditions
Stable viscosity enables long oil life and equipment protection at high and low temperatures
Filterability

- Evaluated based on results of:
  - Dry and Wet Filterability (ISO 13557)
  - Internal filtration method

Maintaining filterability even in the presence of water is critical in applications where water contamination may occur.
Water Tolerance

- Water tolerance is an important performance characteristic of a wind turbine gear oil, due to the operating environment.

- Evaluated based on results of:
  - Demulsibility (ASTM D1401)
    - Measures the ability of the oil to rapidly shed water
  - Demulsibility of EP Gear Oils (ASTM D2711)
  - ISO 13357- modified (wet filterability)

Poor water tolerance could lead to lubrication failure due to emulsion formation or oil breakdown under wet conditions.
Foam and Air Release

• Release of air from the bulk oil (air release) and from the oil / air interface (foam) are critical to wind turbine gear oil

• Foam and air release characteristics were evaluated based on
  • Air Release Properties (ASTM D3247)
  • Foaming Characteristics (ASTM D892 I, II, and III)
  • Flender Foam Test (ISO 12152)
    • Assesses air release and foam performance after air is churned into the test oil using high-speed gearbox (~1500rpm) test apparatus

Excessive entrained air in oil prevents proper lubrication and can lead to cavitation in pumps
Poor foam performance could lead to oil leakage from seals
Foam and Air Release

- Flender Foam Test:
  - Volume increase due to entrained air and foam is recorded after 1 minute standing (Pass < 15 %)

![Foam Test Image]

![Volume Increase Chart]

Better
Excessive entrained air in oil prevents proper lubrication and can lead to cavitation in pumps. Poor foam performance could lead to oil leakage from seals.
Rust & Corrosion Performance

- Evaluated based on results of:
  - Copper Corrosion (ASTM D130)
  - ASTM Rust Test (D665)
    - D665A – Distilled Water
    - D665B – Salt Water
    - D665Mod – Syn Sea Water
  - SKF Emcor Bearing Rust Test
    - Distilled Water
      - Result: 0,0
    - 0.5% NaCl
      - Result: 1,1

Oils with poor rust and corrosion performance may not be able to adequately protect steel from rust or yellow metals from corrosion.
Common Industry Trends

- Seals and Fill-for-Life
- Oil filtration
- Test selection for used oils
- Vibration sensor technology
- Failure Modes:
  - White Etching Cracking

White Etching Cracking
- Subsurface damage
  - Occurs without warning
  - Results in component failure with costly repair
- Critical factors
  - Lubrication variables
  - Tribological contact
  - Subsurface conditions
- Working toward improved capability for future prediction and prevention
Summary

• Gear box design and wind turbine application require specific demands from gear oil lubricant

• Capability of a lubricant to meet the required demands depends on formulation approach

• Understanding key focus parameters and appropriate test methods improves gear oil performance in the real world

• Understanding impact of failure modes and the lubricant’s role in prevention will continue to enable the next generation of wind turbine lubricants
Questions?