Wind Turbine Gearbox Reliability - A Materials Tribology Perspective*

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Discussion Topics

1) Wind turbines and the US DOE goal for wind power
2) Tribology as a set of multi-disciplinary problems
3) Wear modes within wind turbine components
4) Friction – wear relationships
5) Transient phenomena in tribo-components
6) Top 10 reasons to study tribology in graduate school
7) 7 challenges in materials tribology for wind turbines
Total US energy consumed in 2007

Source: U.S. DOE, EIA (May 2008)
US renewable sources in 2007

WIND = 4.7 (0.3% overall)

% by energy source

Source: U.S. DOE, EIA (May 2008)
DOE’s 20/2030 plan*

- 20% of US electrical power by wind energy in the year 2030
- Requires an installed wind turbine capacity of 300,000 MW

“Are we there, yet?”

- In 2008, wind energy supplied ~1% of US power
- In 2007: 5,244 MW was installed (beat predictions)
- Industry on track to increase installations to about 16,000 MW per year to achieve the DOE 2030 goal.

Wind power was used to run machinery over a thousand years ago.

A wind paddle device turned millstones in Iran over 1,500 years ago. Several similar structures stand side-by-side.
Two types of wind turbines

VERTICAL AXIS WT

HORIZONTAL AXIS WT
Buffalo Mountain, TN
(near Oak Ridge)
Wherever there are moving parts with surfaces in contact, tribology will play a role ... *sometimes a critical role.*
Material selection and lubrication of gearbox components can be a challenge.

Rolling element bearings of various types within a commercial wind turbine gearbox
Tribology is a field that contains diverse multi-disciplinary problems

Core Engineering Subjects

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<tr>
<th>Physics</th>
<th>Statics / dynamics</th>
<th>Chemistry</th>
<th>Materials science</th>
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<tr>
<td>Mathematics</td>
<td>Metrology</td>
<td>Unit operations</td>
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<td>Machine elements</td>
<td>Thermodynamics</td>
<td>Computer science</td>
<td>etc...</td>
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- Specialists in Mechanics and Mechanical Design
- Specialists in Chemistry and Lubrication Engineering
- Specialists in Materials, and Surface Treatments
- Specialists in Tribophysics and Nanoscale Phenomena
- Specialists in Sensors and Diagnostics (Tribotronics)
Lubrication Engineering cover reprint: January, 1986
Tribology – an enabling field for wind

• For wind energy to become widespread and practical, wind turbine components must perform well for at least 10-20 years without major down-time and costly repairs.

• Gearboxes sustain significant accelerations and decelerations. Special challenges exist in understanding and modeling transients.

• Multi-disciplinary approaches are required for effective gearbox design, materials selection, surface engineering, lubricant selection, condition monitoring, friction analysis, and real-time control systems.

• Understanding and coping with a variety of potential modes for wear and surface damage in an endless variety of mechanical systems will challenge the next generation of tribologists.
In tribology, the first step is to define the problem—then decide what disciplines (‘tools’) are appropriate to solve it.

“When all you have is a hammer, all problems look like a nail.”

When you’re focused on EHL films, all tribology problems look like solving the Reynolds equation or calculating the $\Lambda$-ratio.

When you’re focused on asperity deformation, all tribology problems look like the Hertz equation or JKR model.

When you’re focused on wear, all tribology problems look like the Archard equation.

When you’re focused on lubricant development, all tribology problems look like a Shell four-ball testing issue.

These might be places to start, but may not be sufficient.
Several different forms of wear can occur on different parts of the same bearing component (e.g., outer race of a double-row SRB)

Potential causes: abrasive wear, Hertzian contact fatigue, micro-pitting, plastic smearing, fretting, impact wear, tribo-corrosion …
Materials tribology considers interfaces as a materials system

- Bulk material (heat treatment, composition, properties)
- Near-surface region affected by tractions and contact stresses
- Topography and contact mechanics
- Tribochemistry (boundary lubrication)
- Lubricant flow and films (\(\Lambda\))
- Third-body particles
- Material compatibility
- Tribo-formed layers
- Transient phenomena (time dependence)
Understanding the materials’ response to non-steady-state operating conditions

Tribochemistry

Metrology

Physical metallurgy

Mechanical metallurgy

Particle effects / embedment

50.0 μm

0.5 mm

HV PROFILE HRC INDENT CENTER OF ROLLER ID = 1001

Bulk average = 748.4 kg/mm²

INDENTATION EDGE, X = 0

1200

1100

1000

900

800

700

600

500

400

300

200

100

0

0

50

100

150

200

250

X (μm)
Friction and wear are related by energy partition within the tribosystem

Frictional work \( (F \times d) \)

- Heat \( f_h \)
- Elastic deformation \( f_{ed} \)
- Plastic deformation \( f_{pd} \)
- Fracture \( f_f \)
- Vibration \( f_v \)

Wear of two materials couples can be very different even when their sliding friction coefficients are equal.*

Transients: Wear rates may not necessarily be depicted by linear models

\[ V = \frac{kLs}{3H} \]

Archard relationship (ca. 1950)
Friction (torque) in tribosystems varies with time

- Long-term trends in the average friction response
- Shorter-term fluctuations (many possible causes)
A literature survey revealed 8 common forms of friction versus time behavior*

Concurrent interfacial processes require different sliding times to reach steady-state; hence, friction curves are complex.

- Asperity deformation
- Film disruption or removal
- Macro-geometric changes
- Microstructural texturing
- Work-hardening
- Interfacial transfer
- Third-body accumulation
- Surface fatigue processes

Combination of processes at a given time
Friction Process Diagrams\(^*\) account for changes in controlling wear processes.

Like it or not, we don’t live in a steady-state world. Things are changing all the time.

Tribological concepts evolved from visions of quasi-static situations (spheres on spheres with no relative motion), to more complex, dynamic situations more representative of real-world devices.

So, what motivates us to study materials tribology?
Top 10 Motivations for Tribology R&D

(1) Because it’s never been done. (e.g., space program, nano-devices, enabling new designs)

(2) To correct errors in design. (e.g., bad material or lubricant selections)

(3) Make it bigger and better. (e.g., wind turbines, large structures)

(4) Make it last longer. (improve product durability)

(5) Health issues (e.g., remove asbestos from brakes)

(6) Improve! Improve! Improve! (e.g., optimize performance)

(7) Curiosity about how animals work. (e.g., gecko feet)

(8) Force machines to work in ways for which they were not originally designed. (existing transmissions with new, bigger engines)

(9) Solutions in search of a problem. (e.g., ‘What can I do with the new hard coating I just discovered?’)

(10) Simply because it’s interesting! (scientia gratia scientiae)
7 Challenges in Wind Turbine Materials

Tribology

1) Understanding the effects of complex loadings and transients on the dominant surface failure modes in gearbox bearings.

2) Developing transient-based test systems that are applicable to WT.

3) Determining whether hydrogen embrittlement is a significant concern for life reduction in bearings for WT. If so, what?

4) Micropitting: its causes and control.

5) Better understanding of the interaction between lubricants and bearing materials in WT operating environments.

6) Third-body control in WT gearboxes undergoing wear.

7) Optimizing running-in practices for improved operation of gearbox components.