EE5940: Wind Essentials

Materials and Structural Reliability

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Mechanical Engineering
Overview

Focus on Rotor Blades

“the most complex structural component of a wind turbine”
What are the loads on a rotor blade?

- Variable wind speed along the tip of the blade
- Loads are both static and dynamic (varied wind speed, and rotation)
- Flapwise bending
- Cantilever bending
What is the Blade Size?

SHEFFIELD/SUTTON
- Tower = 78 meters
- Rotor diam. = 99 meters
- Sweep area = 1.3 acres (strobe lit)

EARSBURG
- Tower = 40 meters
- Rotor diam. = 40 meters
- Sweep area = 0.3 acres (no lights)

198 feet 418 feet 305 feet

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Desirable Rotor Blade Features

Size
Desirable Material Properties

**Rotor Qualities**
- Size
- Lightweight
- Stiff
- Strong
- Complex Shape
- Long Fatigue Life

**Material Properties**
- Modulus
- Density
- Fracture toughness
- Specific Strength ($Y/\rho$)
- Specific Stiffness ($E/\rho$)
Modulus, Strength, Toughness

Comparison of Stress/Strain Behavior of Steel & FRPs

- **Modulus**: slope
- **Strength**: maximum stress
- **Toughness**: area beneath curve
Materials Selection

Merit index for a beam

\[ M_b = \frac{\rho}{E^{1/2}} \]

Considerations of beam weight (f(\(\rho, t\))) and stiffness (f(E, \(t^2\)))

GFRP: Glass fiber reinforced plastic
CFRP: Carbon fiber reinforced plastic
Other Considerations: Strength vs. Toughness
Composite Materials

Layers with Directional properties

Fibers with a polymer matrix

Heat, pressure

Laminate

Add core material for stiffness in bending

Samples of material, laminates, core materials
Composite Materials

Fibers

Specific strength: $Y/\rho$

Specific stiffness: $E/\rho$

Resins

Thermosets (epoxy, heat cured)
Thermoplastics (can be reheated and reformed)
Anatomy of a Rotor Blade

Generic blade cross section

- Fiber reinforced material
- Balsa wood/foam
- Material transition zone

How should fibers be oriented?
Blade Manufacture: VARIM

Vacuum Assisted Resin Infusion Molding
Forming the shell

Laying up woven fiber sheets

Resin infusion
Finishing steps

Completed blade halves are bonded together, surface checked for smoothness.

Interior webs provide shear stiffness.
Improvements in Manufacturing Lead to Reduced Weight
Health Monitoring

Cost effective Wind Energy: Critical to achieving the 2020/30 DOE goal

- Reliability leads to reduced costs: Health monitoring and early fault detection can reduce maintenance costs and system downtime

- Condition Based Maintenance (CBM): System-wide sensors, mathematical models, and fault detection algorithms are key to improved cost effectiveness
Approach to Health Monitoring

Performance Assessment (sensors)

Estimate/Predict Performance (algorithms, system models)

Compare sensor data with expected performance

Detect Incipient Failures

**Blade:** Fiber optic strain sensors

**Gearbox:**
- Accelerometers, tachometer

**Generator:** current, voltage

**Controller/Data Collection**

**Model based Observer**

**Data Acquisition**

**In Nacelle**

**Additional Environmental Sensors**

**Blade control:**
- Hydraulic pressure, temperature, and flow sensors

**In Nacelle or Ground**

**Remote**

**PC-GBS**

**Internet**

**2.3 mW Siemens Turbine**
- Main Rotor Bearing
- Gearbox
- Generator
- High Speed Shaft
- Brake
- Yaw Drive
- Blade
- Pitch/brake hydraulics

**In Nacelle**

**Generator:**
- Current, voltage

**Gearbox:**
- Accelerometers, tachometer

**All turbine sensor data**
Real time Evaluation of Blade Health

Sensor Location

Various types of sensors

Strain Gages
Acoustic Emission
Accelerometers
Smart Materials (PZT)

Where do you expect failure?
Sensor Locations (1)
Sensor Locations (2)
Sensor Locations (3)
Turbine Health Monitoring: Jobs

• **Wind Farm Operations & Maintenance**
  – 40% of long term “direct” employment
  – 80,000 jobs predicted by 2030
  – Assumes 20-year turbine life
  – Wind farm developers offering aftermarket services

• **Economic Benefits of CBM/Health Maintenance**
  – Early fault detection → CBM (Condition Based Monitoring)
  – Avoid costly repairs & lead time
  – Common repair, maintenance & overhaul profile
  – Skilled U.S.-based workforce vs. overseas aftermarket shops

• **Job Impact for Sensor, Data acquisition & Analysis**
  – Engineers: sensing & control subsystems
  – Knowledge workers: on-site / remote monitoring
  – 3rd party providers: asset management and CBM
Clicker Quiz

Which of the following properties is NOT important when selecting a material for wind turbine rotor blades?

a. Toughness  
b. Density  
c. Specific heat  
d. Modulus