Smart Wind Turbine Rotor Blades

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Motivation

• Wind Power is a well established, clean energy source

• Efficiency aim: build larger wind turbines
  – Largest to date: Enercon E-126, d=126m, P=7,5MW

• Size limitation (among others):
  – Structural loads due to gravity and wind
  – Lifespan impact: instationary gust loads
Smart / Adaptive Structures

- **Sensor**: observe a disturbance
  - e.g. wind, acceleration, strain sensor

- **Controller**: determine reaction to achieve desired result
  - e.g. feedback / feedforward controller

- **Actuator**: execute controller command
  - e.g. blade pitch axis rotation, control surface
Dynamic Load Alleviation (aircraft)

- Structural wing model
  - Finite Element Method

- Aerodynamic Wing Model
  - Doublet Lattice Method

- Coupled Aero-Elastic analysis
  - time domain
Dynamic Load Alleviation (aircraft)

- Feedforward controller
  - “Gust sniffer“ in front of the wing
  - Control command on the flaps

- Structural response
  - 30 % peak load reduction
Dynamic Load Alleviation / Noise Reduction (Helicopter Blade)

- „Smart“ Helicopter rotor blade
  - Piezo-actuated Trailing edge
    - +/- 6° deflection
  - Reduced Blade loads
  - Reduced Noise Level
Morphing Control Surfaces

- Plain flaps vs. Morphing Flaps

- Benefits:
  - Reduced Drag, increased Lift
  - More generated power with same structural loads
Airfoil morphing

Sample reference rotor: AOC 15/50 – Layout and airfoils:

Adaptation using a generic elastoflexible airfoil

See Poster by Institute of Aerodynamics and Fluid Mechanics!
Transient Wind Loads (Video)

NREL 5 MW reference turbine
hub height: 90 m, rotor diameter: 126 m, mean wind speed: 12 m/s
Transient Wind Loads (Video)

NREL 5 MW reference turbine
hub height: 90 m, rotor diameter: 126 m, mean wind speed: 12 m/s

Graph showing wind speed over time.
Effects of gust load alleviation on a wind turbine blade

- NREL 5 MW reference turbine, Lee et. al., KAIST, Daejeon, Korea
Challenges

• Reliability
  – If the control system fails, the turbine can not be operated without the risk of damage

• Cost
  – Additional hard- and software is needed

• Power Requirements
  – Energy consumption of the controller and the actuators must be kept low
Conclusion

• Smart Rotor Blades are able to reduce peak loads

• Aerodynamically efficient control surfaces: Morphing Flaps

• Combined: Larger and more efficient wind turbines
Thank you – Questions?
BACKUP SLIDES
Passive Solution: Elastoflexible wing

Concept

• Internal Support Structure
• Elastic membrane skin as aerodynamic surface

Reasoning

• Large shape variations are possible with low effort
• passive flow control through load-dependent membrane deflection

Source: TUM Institute of Aerodynamics and Fluid Mechanics & TUM Institute for Computational Mechanics
Dynamic Load Alleviation (aircraft)

Feedforward adaptive filtering → Learning capabilities for specific input signal

→ Response on discrete gust triplet with adaptive filtering

→ Peak reduction increases with time, as filter parameters are adapted

→ ~ 50% Peak reduction
Windenergieanlagen: morphing / adaptive rotors

Membrane wing – “Morphing“ (Airfoil adaptation; passive load control)
Dynamic Load Alleviation of wing-like structures in unsteady flow fields

→ Feedback controller
  • Feedback of acceleration sensor signal at the wingtip
  • 2nd order transfer function for damping of the 1st bending mode
  • Control Command on Trailing Edge Devices

→ Structural response:
  • ~10% reduction of first peak in bending moment, but very strong reduction of following peaks
  • Highly efficient damping of a steady vibration
  • Low efficiency of highly transient response