Full scale blade testing at WMC

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Knowledge Centre WMC

Wind turbine Materials and Constructions

Overview

- Purpose of full scale blade testing
- Determining mass and COG
- Natural frequency and modal analysis
- Static tests
- Fatigue test(s)
- Post-fatigue static tests
- Blade test simulation and analysis in FOCUS6

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Purpose of full scale blade testing

To demonstrate that the design and production of a blade type is sound:

- Show that the blade can withstand both the design *ultimate* and the *fatigue* loads
- Prove the validity of the design models:
  - Mass and COG
  - Natural frequencies
  - Static deflections

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Purpose of full scale blade testing

Design assumptions simultaneously checked:

- The stresses or strains are calculated accurately or conservatively estimated
- The classifications of strength and fatigue resistance of all relevant materials and details are estimated accurately or conservatively
- The strength and fatigue formulations used to calculate the strength are accurate or conservative
- The production is according to the design

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Purpose of full scale blade testing

What is not tested:

- The validity of the design loads
- Effects due to environmental conditions that are different during testing
- The scatter in the results
- Possible changes in the production or design

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Full scale blade test program

Proposed minimum test programme according to *IEC 61400-23*:

- Determining mass and COG
- Natural frequency and modal analysis
- Static tests
- Fatigue test(s)
- Post fatigue static tests

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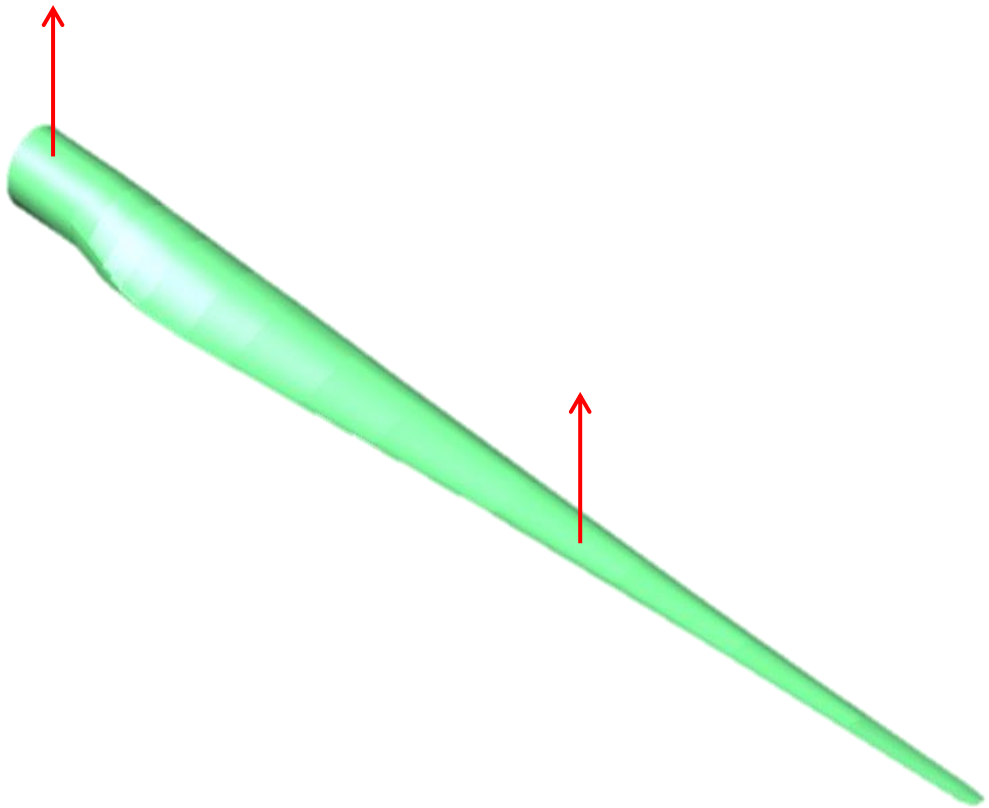
Determining blade mass and COG

Blade is hoisted at two points

Lifting loads are measured by two loadcells



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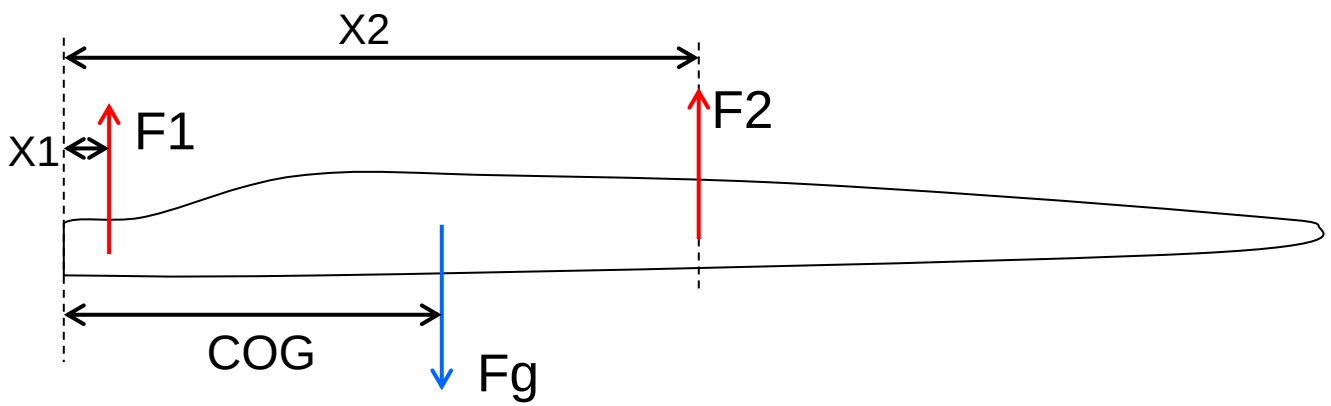
Determining blade mass and COG

Calculation of weight and COG:

Fg = F1 + F2

COG = (X1*F1+X2*F2)/Fg



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Natural frequency and modal analysis

Determine:

- Blade natural frequencies
- Mode shapes
- At least first two flap and edge frequencies

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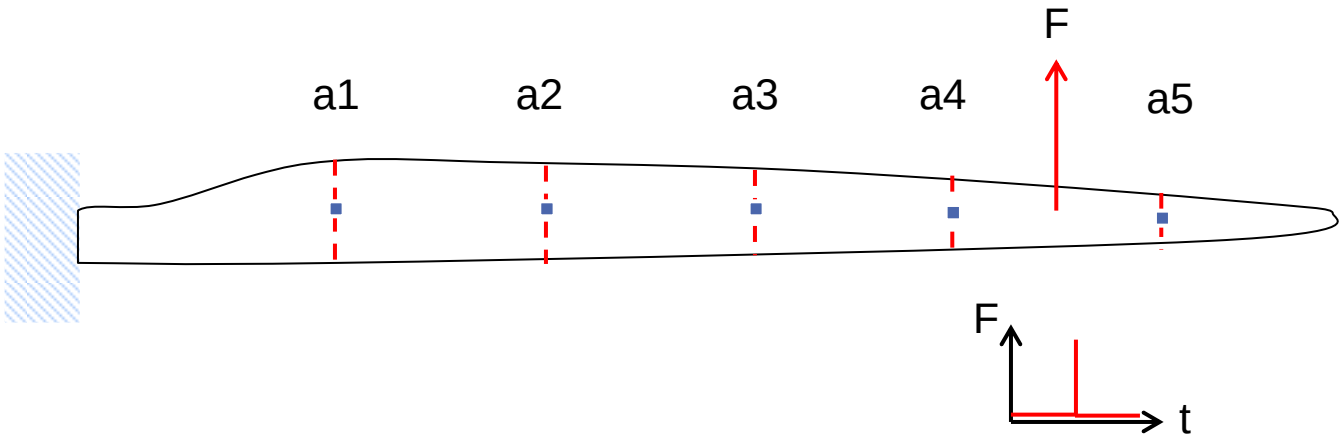
Natural frequency and modal analysis

Setup:

- Blade is fixed at the root
- Accelerometers are placed at multiple cross-sections
- Blade is given an impact at one location



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Natural frequency and modal analysis

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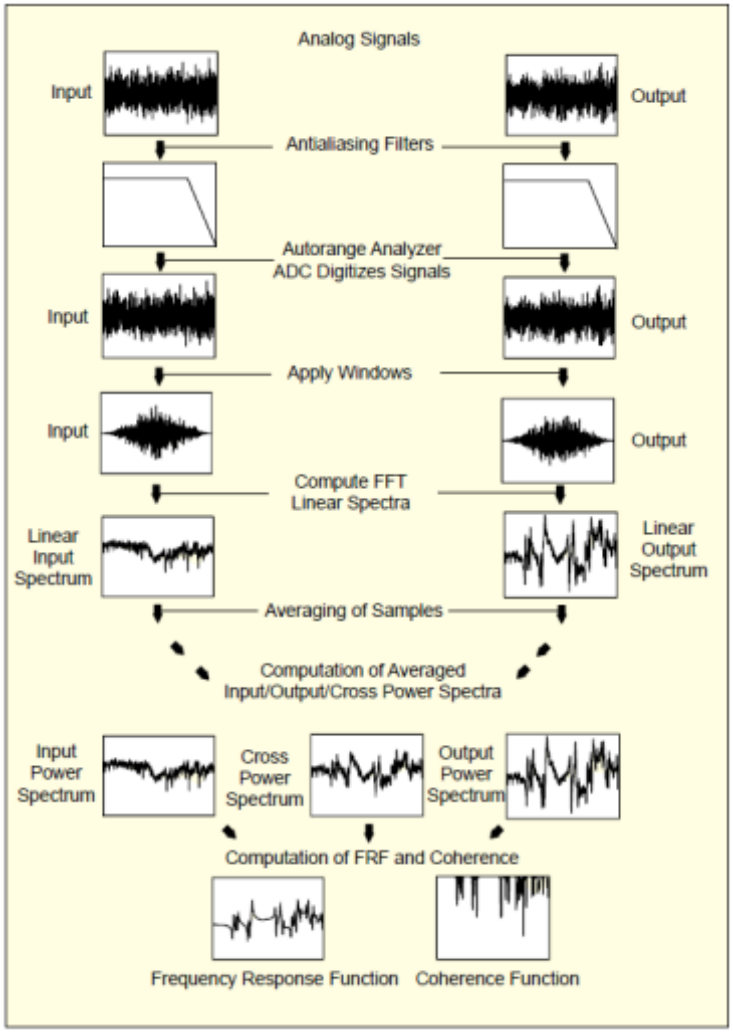
Natural frequency and modal analysis

Time signals of impact and accelerometers are converted to the frequency domain (FFT)

Ratio of the input and output spectrum gives the frequency response function (FRF)

H(s)=a1(s)/F(s)



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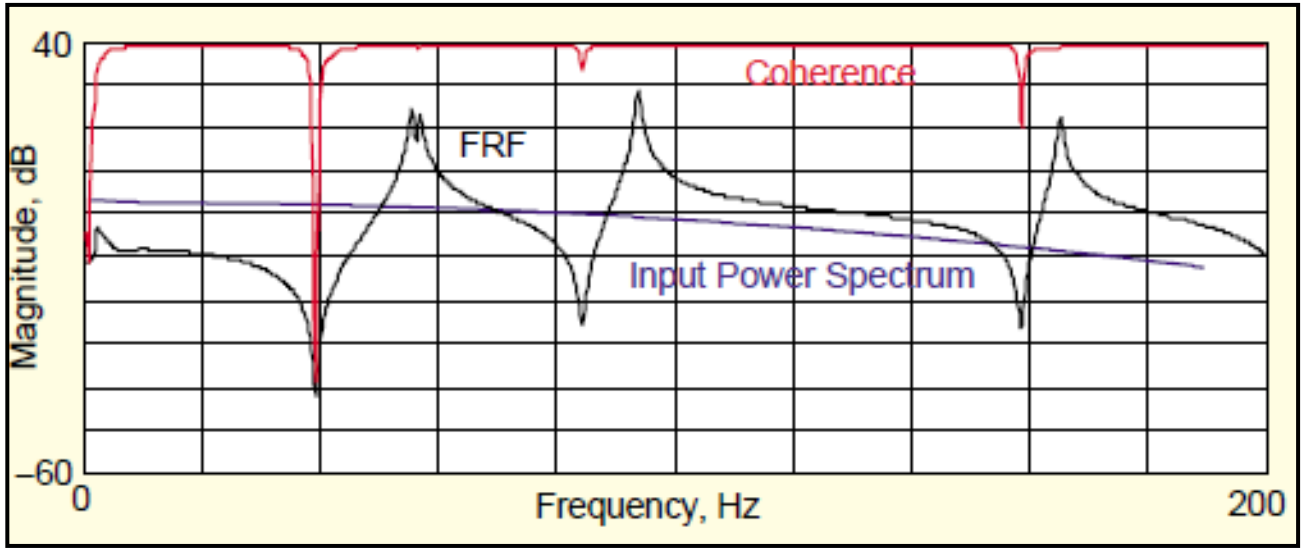
Natural frequency and modal analysis

Frequency response function:

- Natural frequencies show up as resonance peaks
- Combining the FRFs for all measured locations gives the mode shapes



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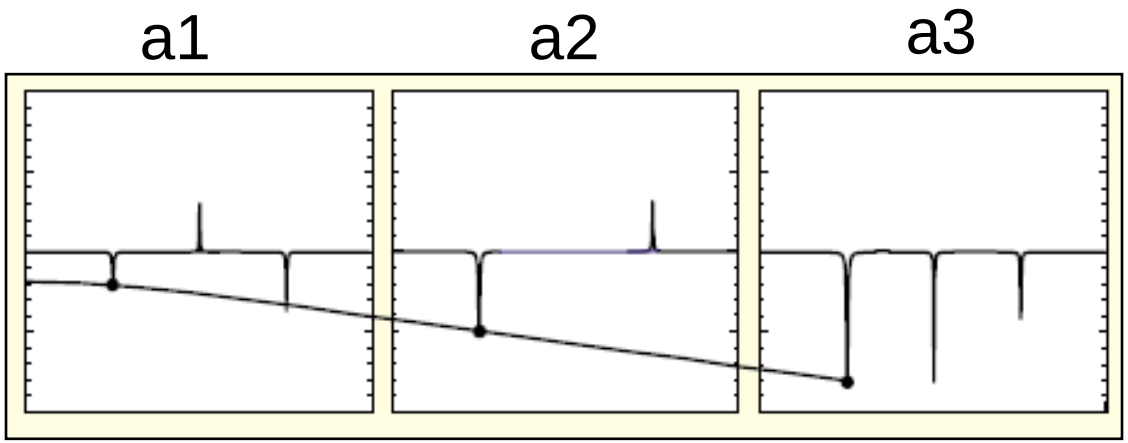
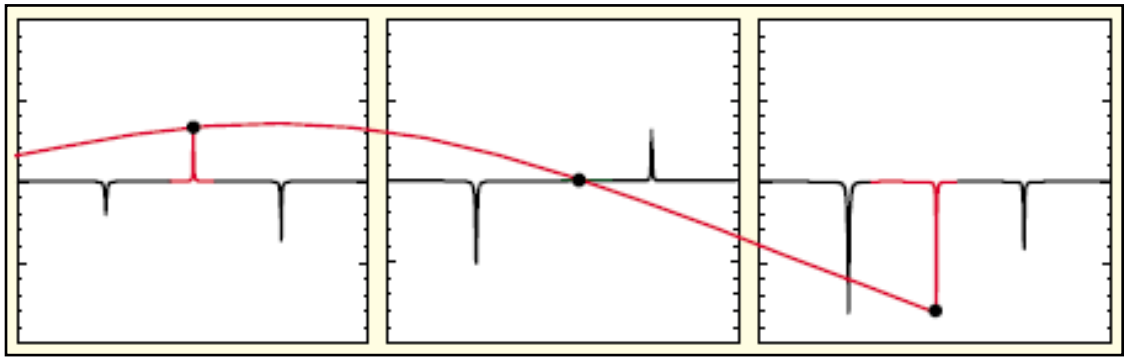
Natural frequency and modal analysis

First mode:



Second mode:



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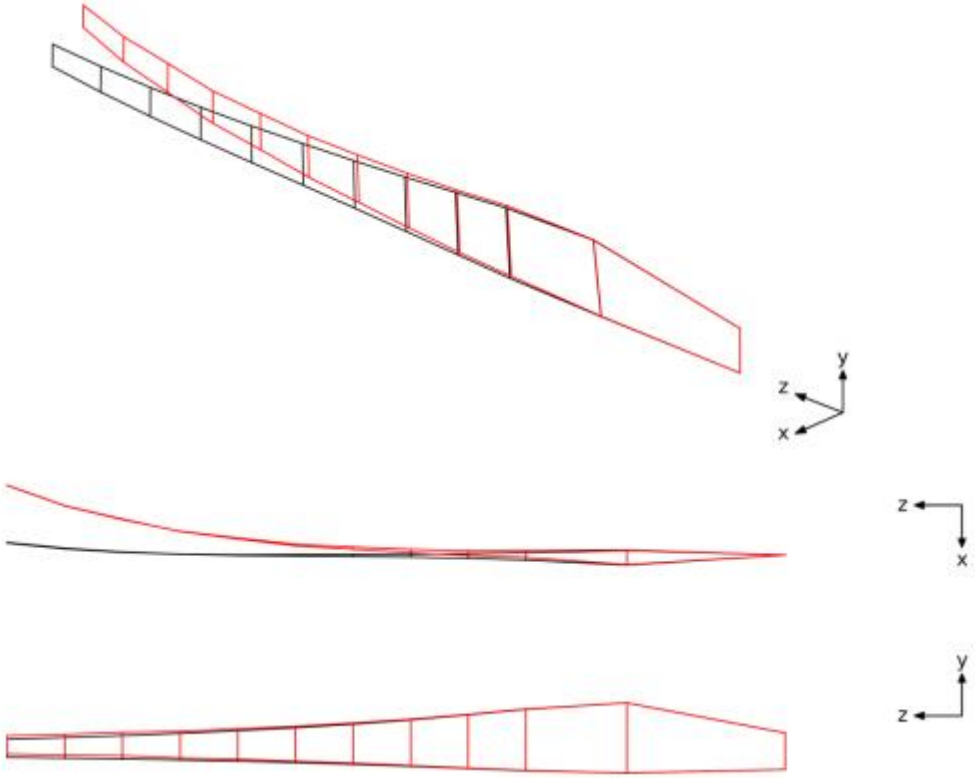
Natural frequency and modal analysis

Example of resulting mode shape:



Measuring accelerations in three directions results in mode shapes with combined flap, edge and torsion

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Static tests

Goals static test:

- Show blade can withstand ultimate design loads (i.e. ultimate limit state is not reached)
- Compare model strains and deflections to measurement

Design ultimate moment curve is derived from turbine load set (FOCUS, BLADED)

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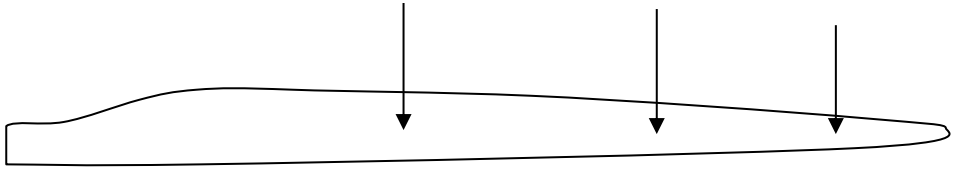
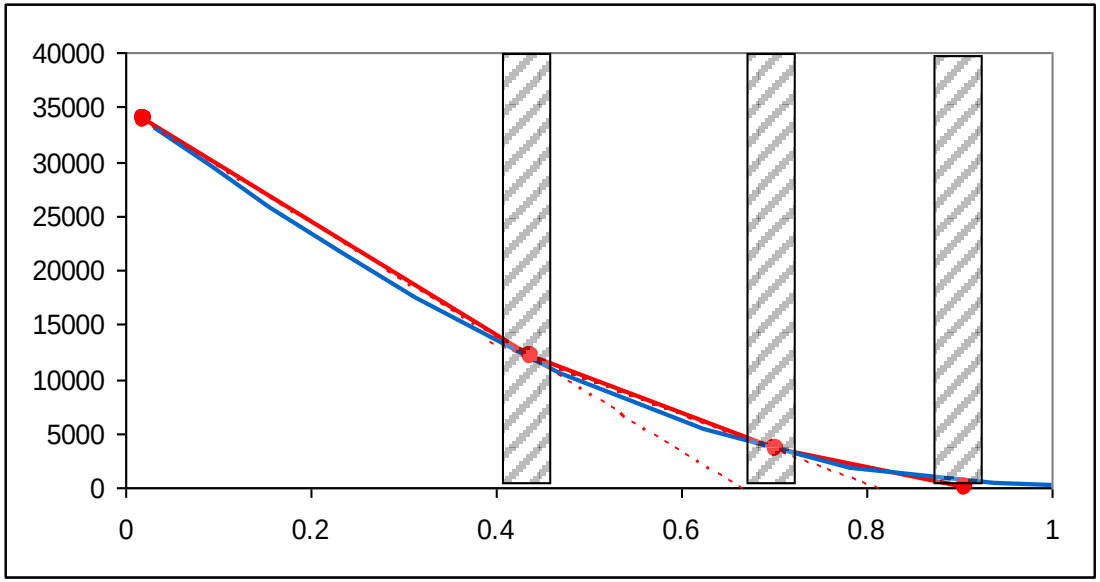
Static tests

Static moment distribution is approximated by multiple point loads





Not properly tested

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Static tests

Test setup:

- Blade is fixed at the root (via blade bearing)
- Blade bolts are instrumented to measure loads in bolts during test
- Strain gauges are placed at various locations along the blade (typically 100+ channels)
- Wire transducers are used to measure blade deflections (in 3D)

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Static tests

Static loads are applied using load introduction saddles:

- Shaped to local blade profile
- Can not be placed at critical cross-sections
- Loads should only be applied perpendicular to the deformed blade axis
- Loadcells are used to measure applied loads

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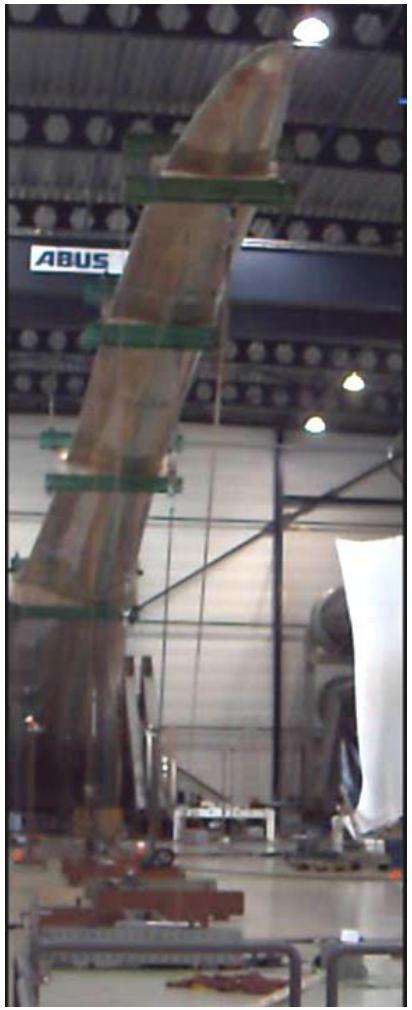
Static tests

Static test example (movie)

- Blade length of 50 meters
- Tip deflection of about 10 meters
- Hydraulic winches used to apply the loads
- Shown at 4 times normal speed
- Load cases in multiple directions
- After each test the blade is visually inspected for damage



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Fatigue test

Fatigue damage due to 20 years design life compressed to a test of approximately 1-2 months:

- Increasing the frequency
- Omitting non-damaging cycles
- Increasing the load

Regular inspections to check and mark blade damage

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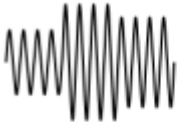
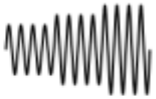
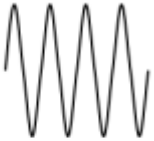
Fatigue test

Variable through constant amplitude

				
Hardware, Load control	Complicated	←		Simple
Loading	More realistic	←		Realistic
Sensitivity to fatigue formulation	Lower	→		High

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Single-axial fatigue test (resonance)

- **Advantages**
  - Simple hardware
  - Simple tuning of bending moment distribution
  - High frequency
  - Low energy consumption
  - Distributed loading
- **Disadvantages**
  - Separate flap and edge test
  - Limited by blade mode shape
  - Not testing total circumference

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Single-axial fatigue test (resonance)

Flapwise fatigue test on the EWT29 blade at Knowledge Centre WMC

EWT Direct Drive Wind Turbines

Knowledge Centre WMC

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Bi-axial fatigue test (near resonance)

- **Advantages**
  - Accurate coordination of flat & edge loading combinations
  - Torsion loading
  - Short test time
  - All R-values, weight compensation possible
  - Moderate energy consumption
- **Disadvantages**
  - More complicated hardware and controlling
  - Tuning of moment curve requires additional hardware

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Bi-axial fatigue test (near resonance)

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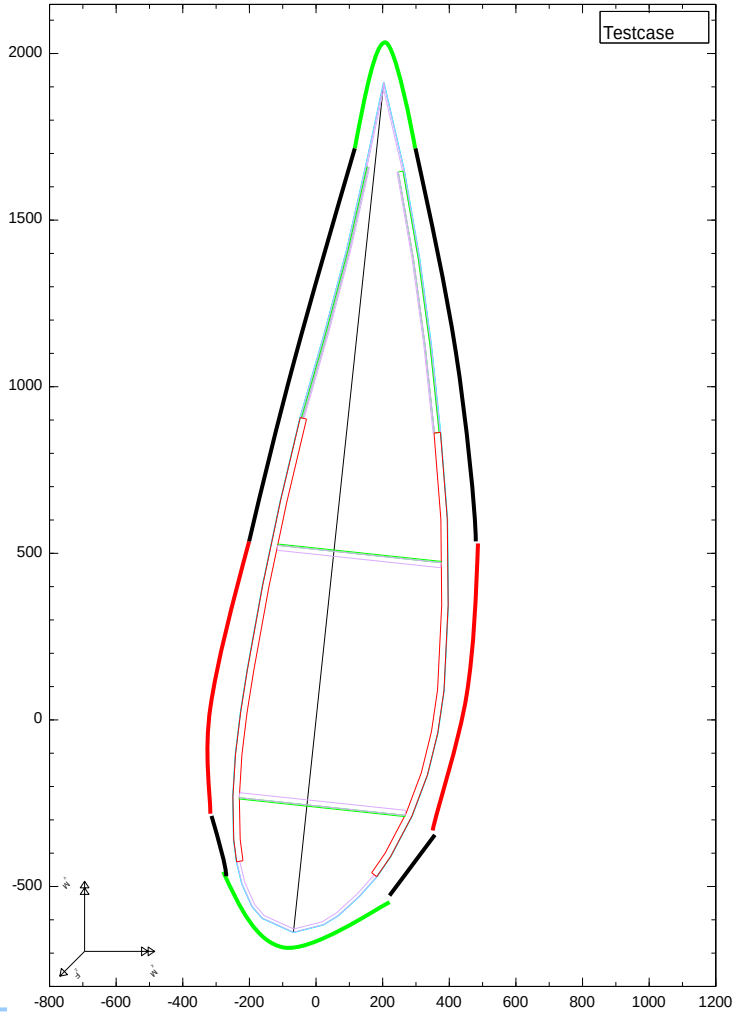
Fatigue test

Single or bi-axial: parts of cross section tested

- Single (flat and edge separately)
- Bi-axial (complete cross section)



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Post fatigue static tests

- Same as previous static tests
- Show blade strength and stiffness is not severely reduced by fatigue damage
- Optionally a test to failure to determine the ultimate limit state

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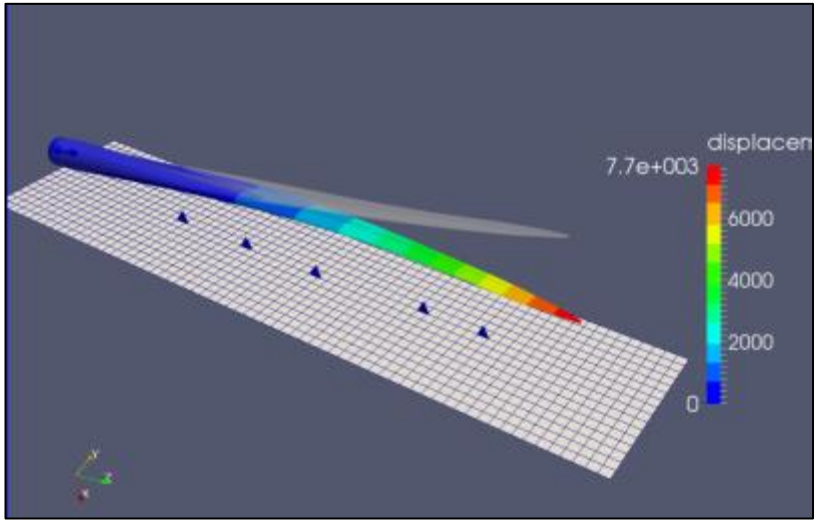
Blade test simulation and analysis in FOCUS6

Design of static test set-up:

- Determine blade deflections under design loads
- Calculate location of ground points of cables

Compare model to static test results:

- Directly recreate test loadcase from measurement data
- Compare deflections
- Compare strains



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Any questions?

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