Integrated dynamic testing and analysis approach for model validation of an innovative wind turbine blade design

2018 Simcenter Nordic Conference
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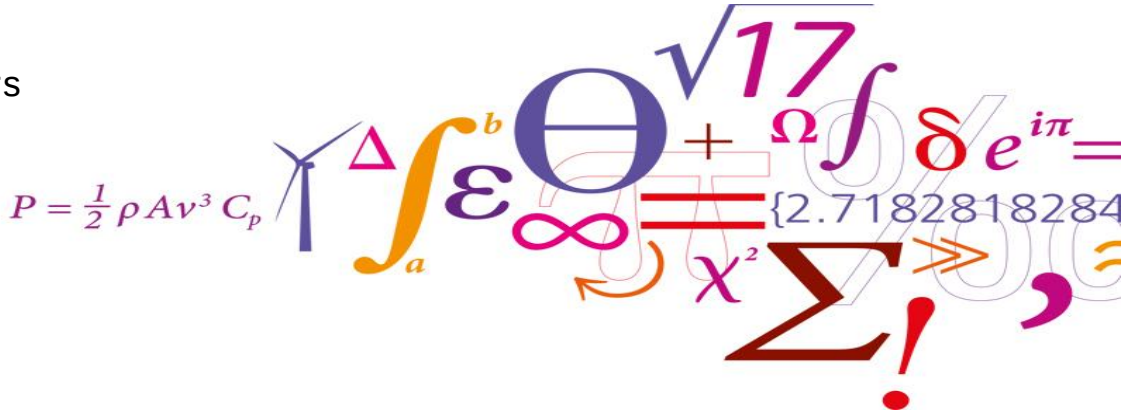
CEKO Sensors:
Kasper Reck-Nielsen

DTU Wind Energy:
Peter Berring, Marcin Luczak

DTU Wind Energy
Department of Wind Energy

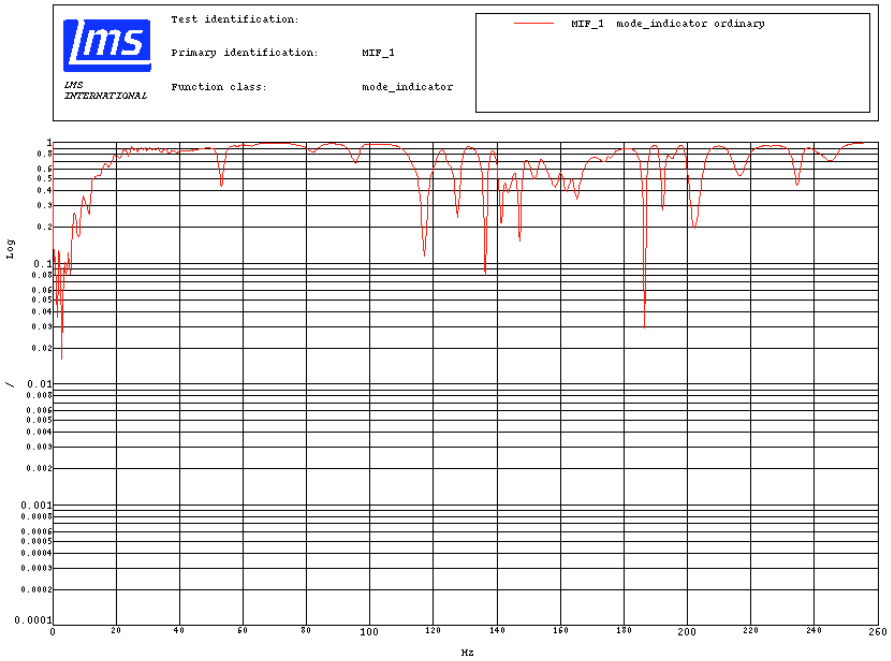


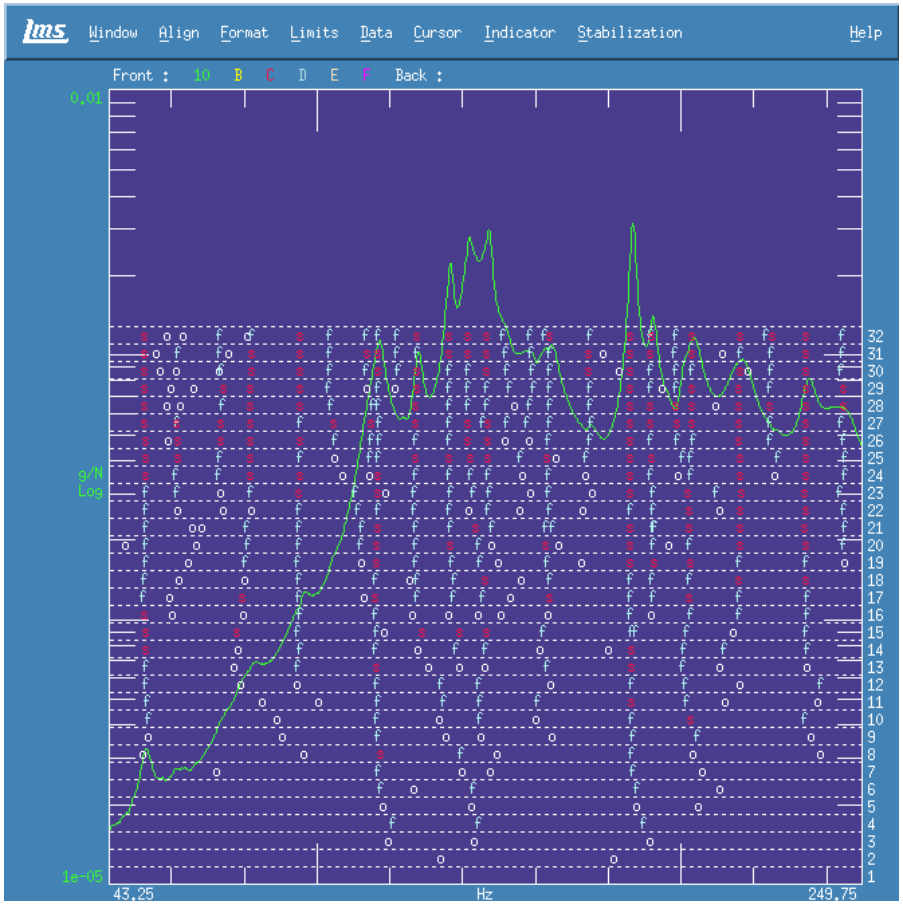
Presentation outline

- Introduction to DTU Wind Energy
- Motivation and objectives
- Research team
- Object of investigation
- Test setup
- Results
- Conclusions
- Future outlook
- Acknowledgements

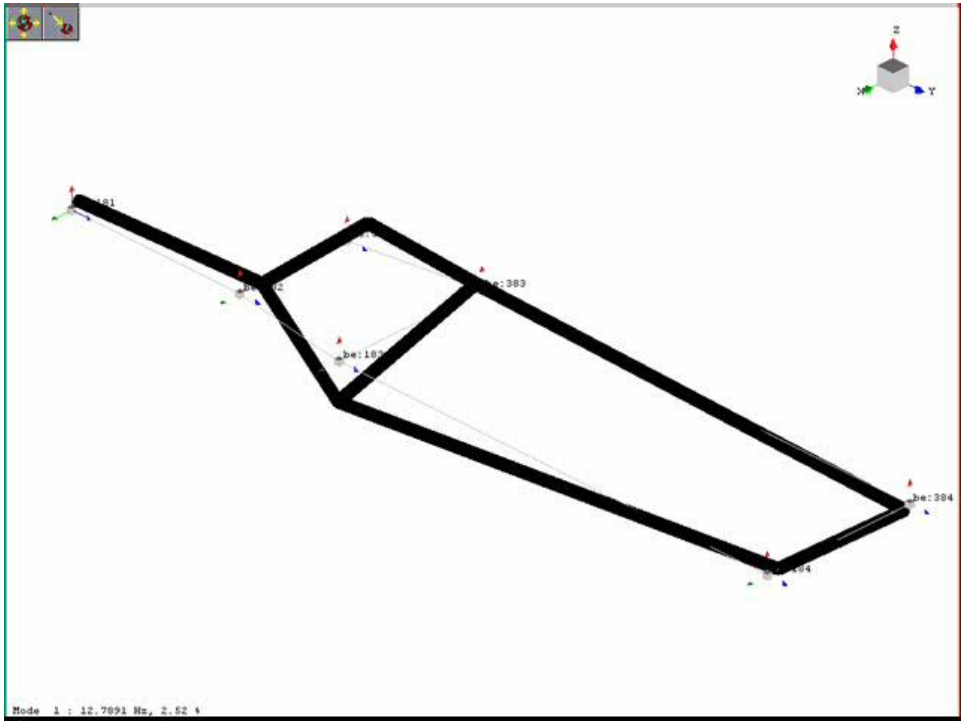
Few years ago

Few years ago





Few years ago



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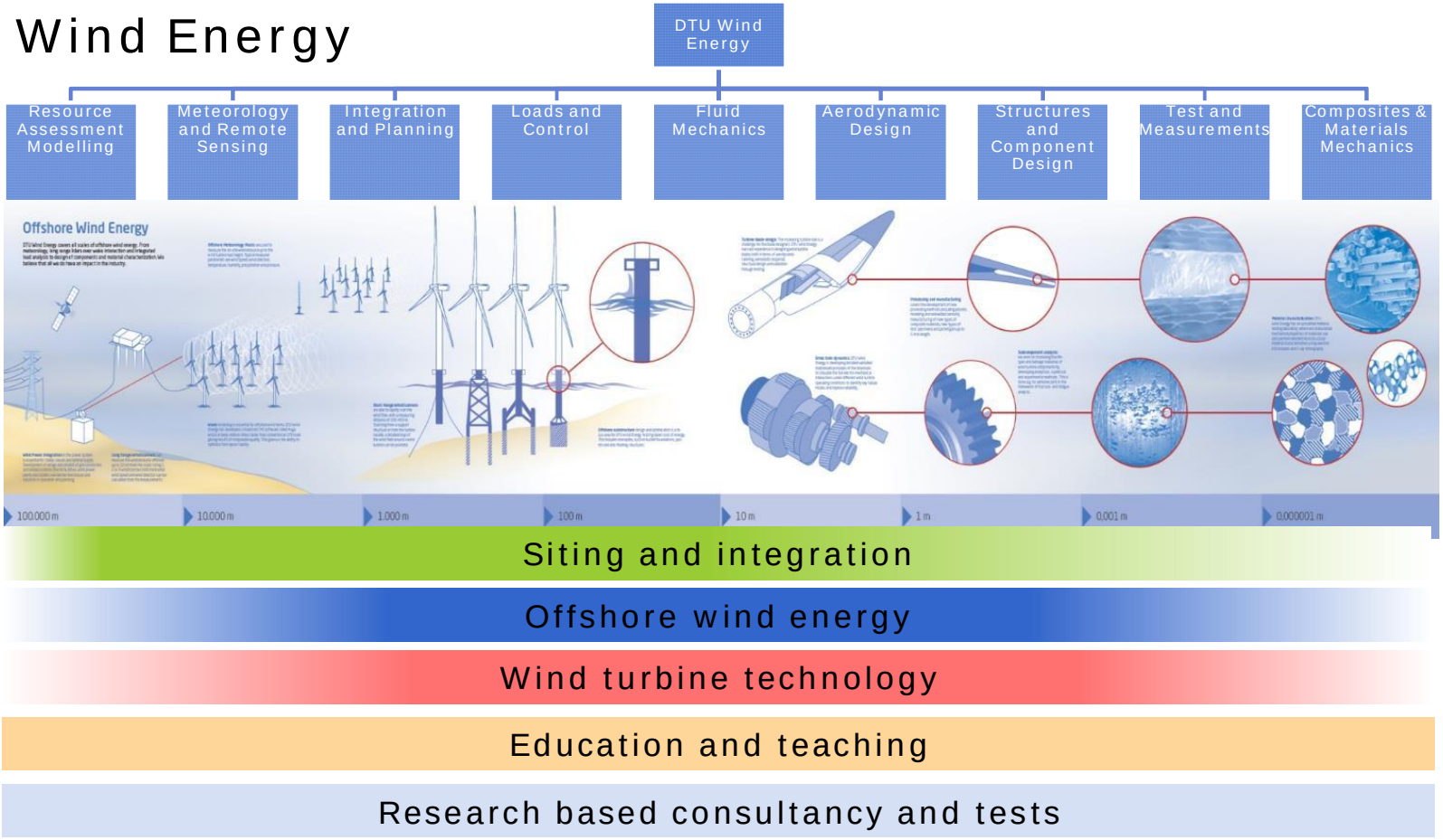
Østerild Test Centre 2014

DTU Risø Campus

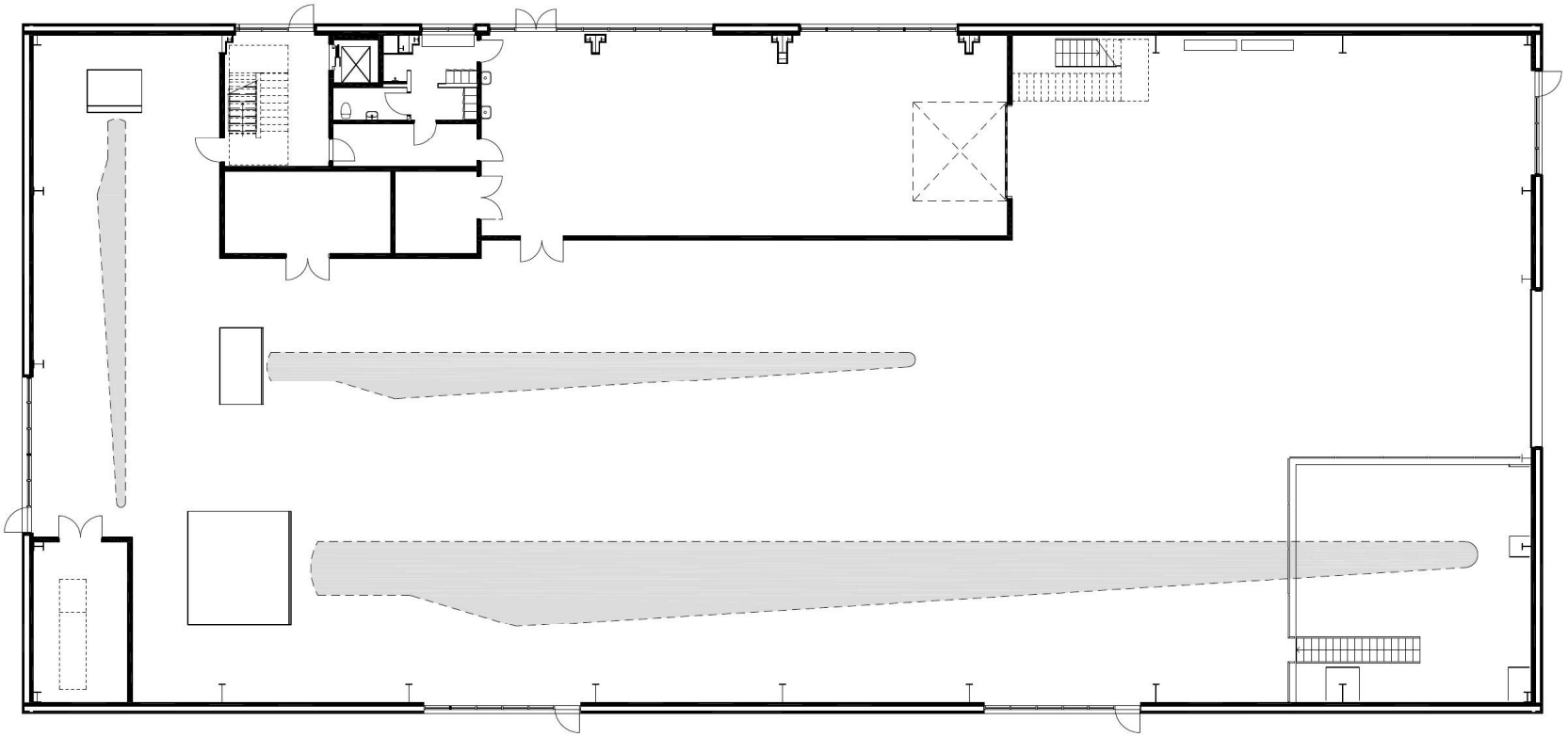
Høvsøre Test Station 2014

DTU Lyngby

DTU Wind Energy




Part of Villum Center for Advanced Structural and Material Testing (CASMaT)
← 301, 309, 325
← 763, 765



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	45 m test stand	25 m test stand	15 m test stand	
Maximum bending moments on test stands				
Static	20.0	3.5	1.0	MNm
Dynamic, amplitude	6.0	1.0	0.4	MNm
Maximum deformations during test				
Static tip deflection	13.5	10.0	5.0	m
Dynamic tip-to-tip	11.0	6.0	4.0	m

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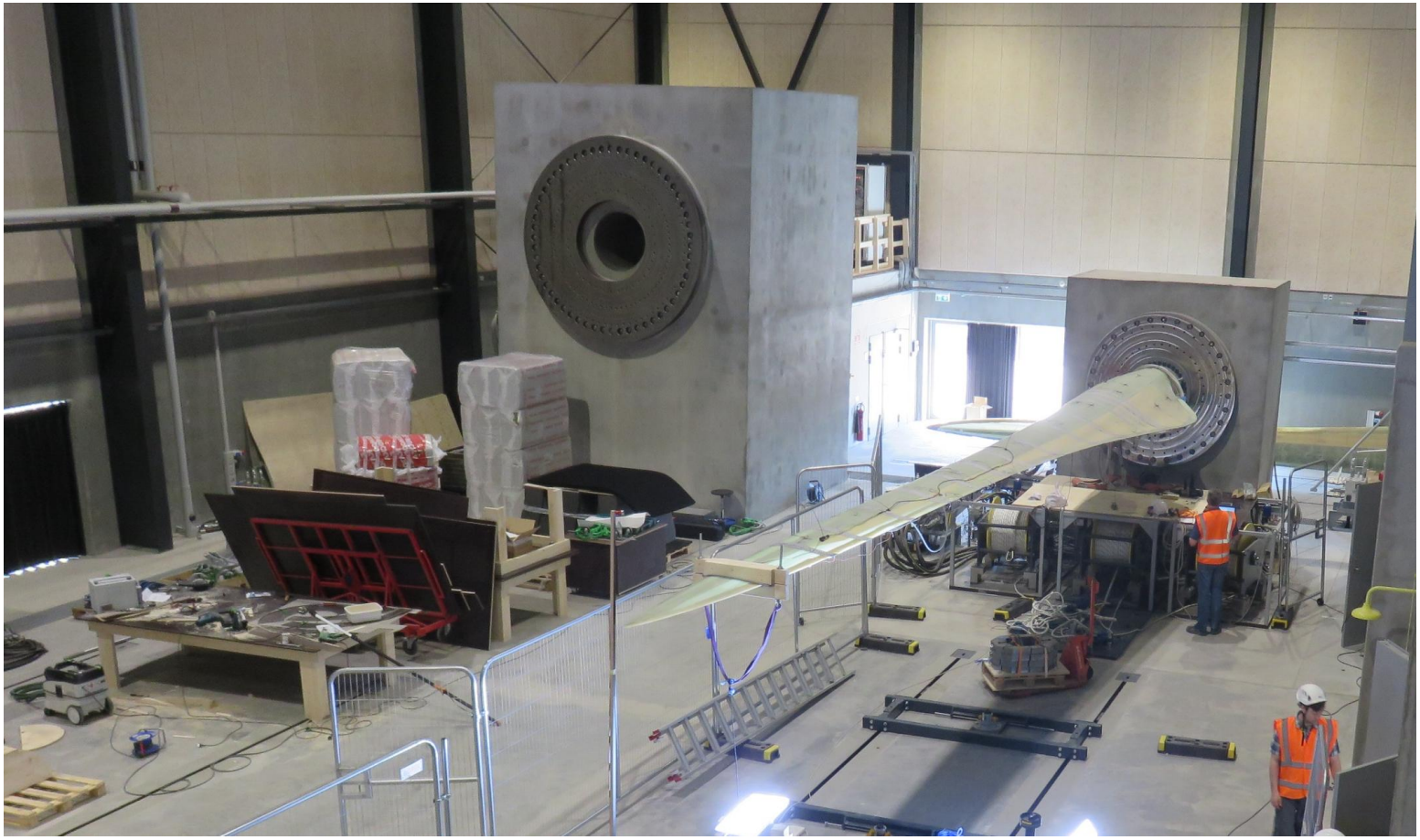


Motivation and objectives

IEC 61400-23:2014 © IEC 2014 – 25 –

10.4.2 Natural frequencies

As a minimum, the first and second flatwise and first edgewise frequencies shall be measured. The mass of the test instrumentation can influence the results of the natural frequency tests.

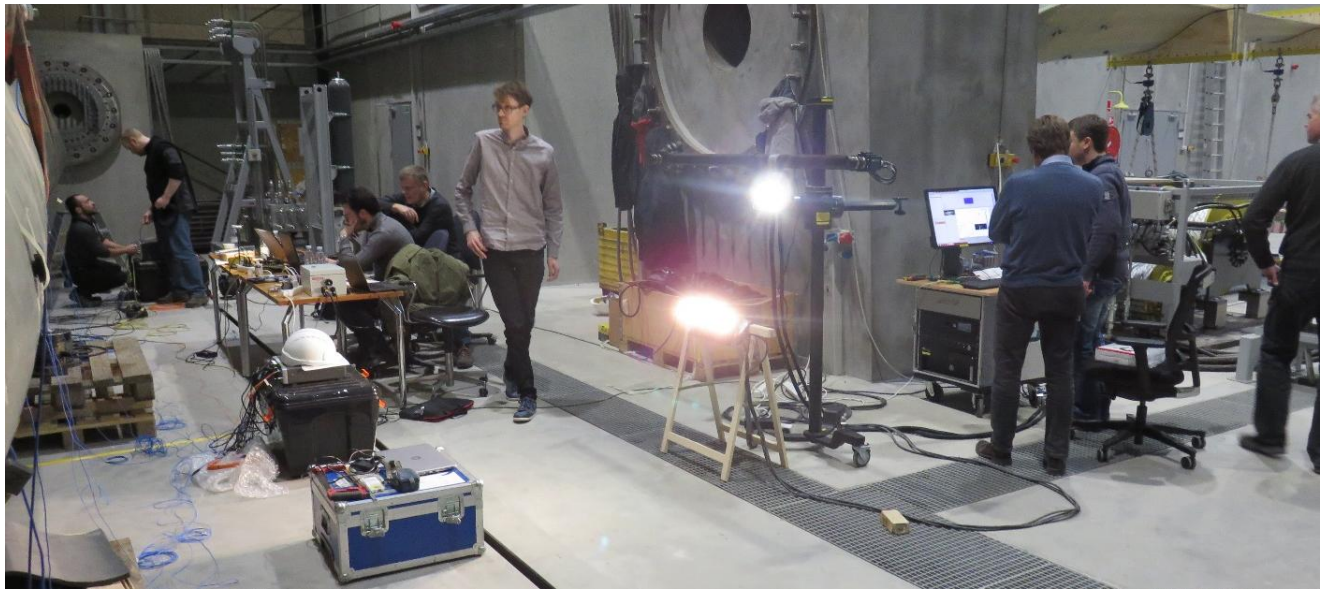
10.4.3 Optional blade property tests

Testing of other blade properties may be of interest. These may include (but are not limited to):

- damping;
- mode shapes;
- creep;
- mass distribution;
- stiffness distribution.

Research teams

- International, Intersectoral and Interdisciplinary



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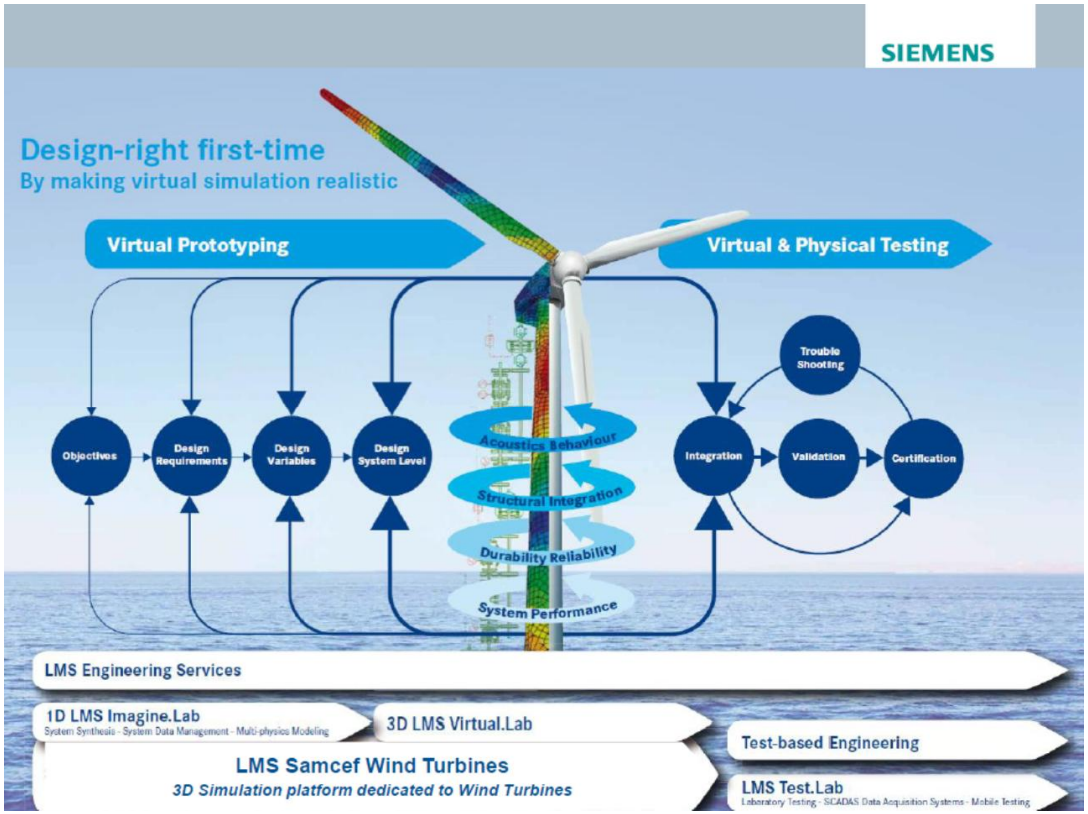
SIEMENS
Ingenuity for life

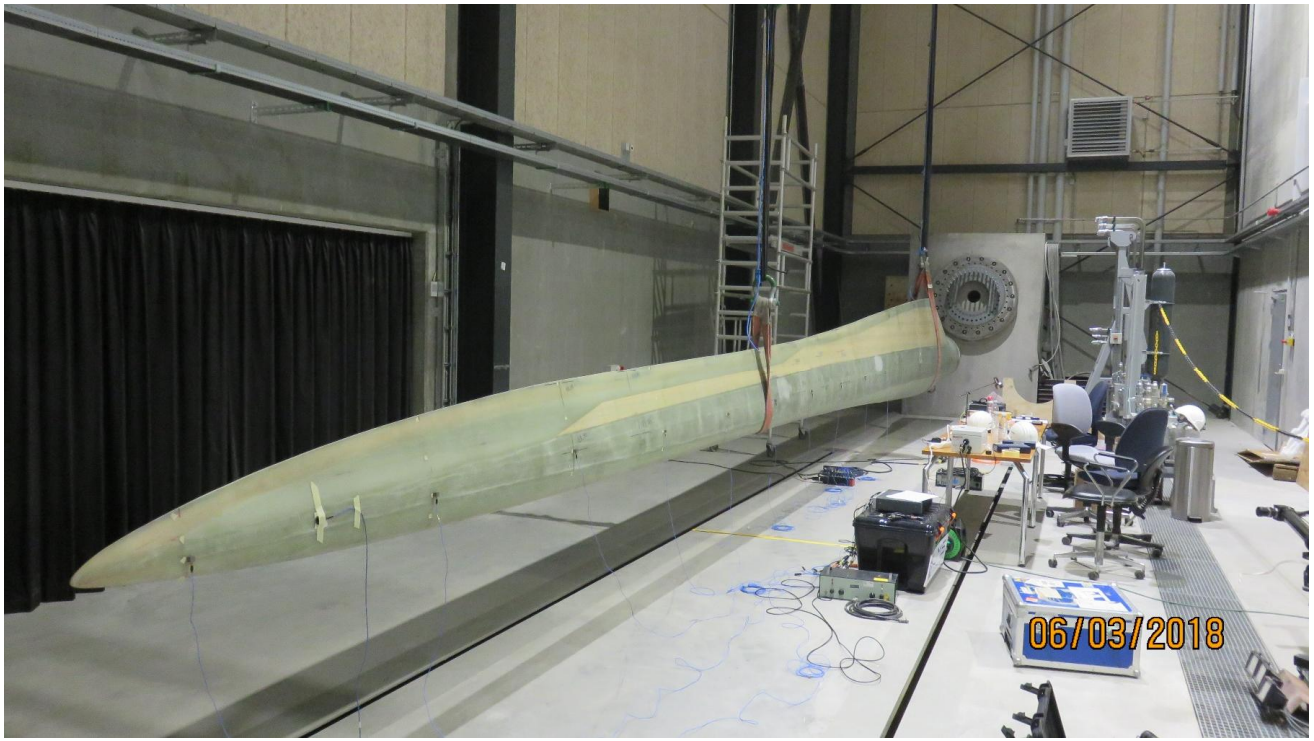
CEKO

Motivation – Digital Twin of the blade



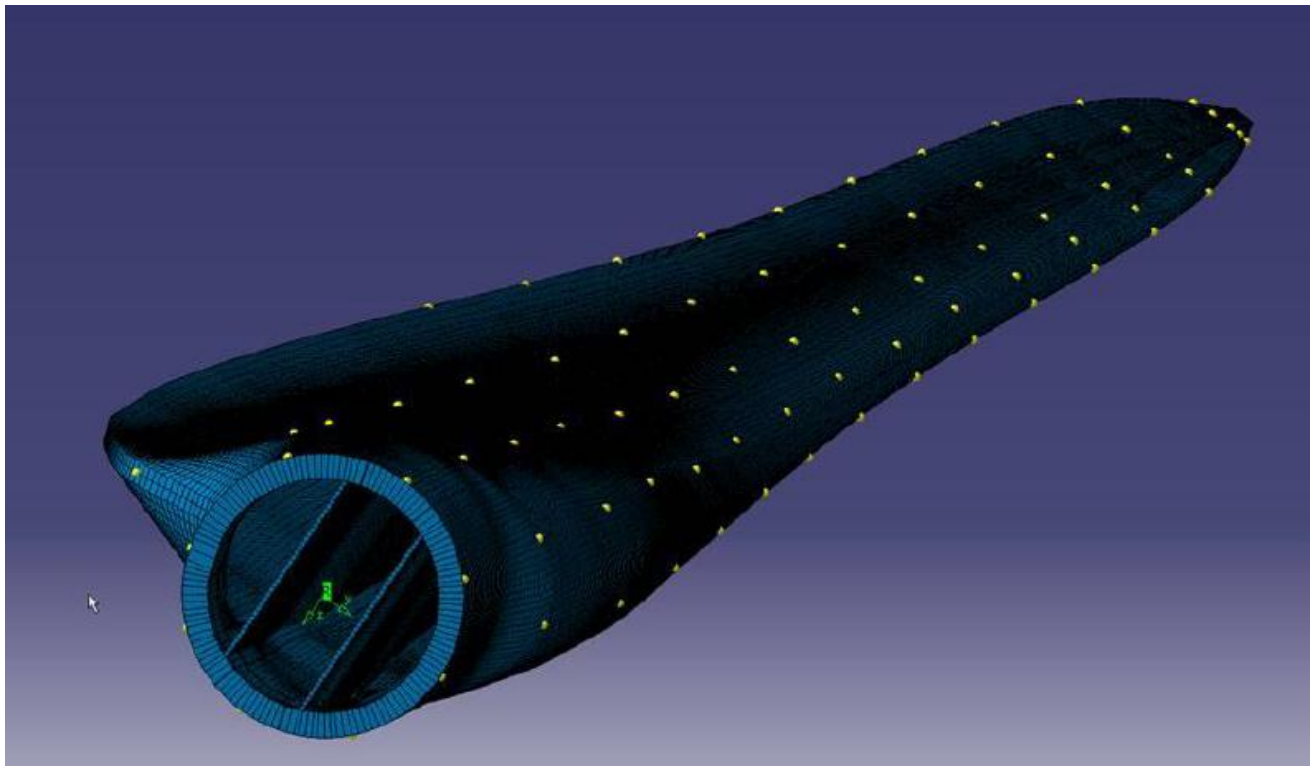
Object of investigation

- Object of investigation

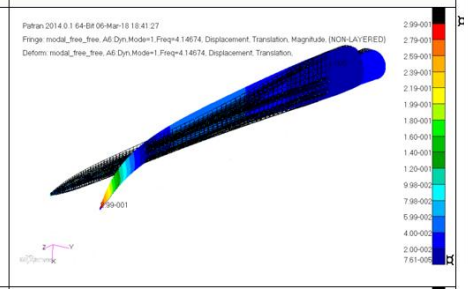
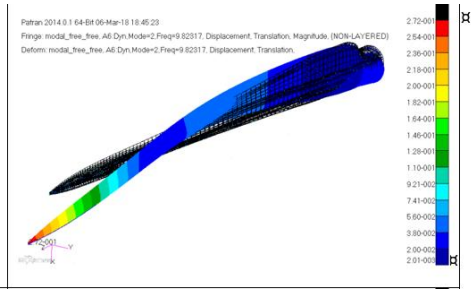
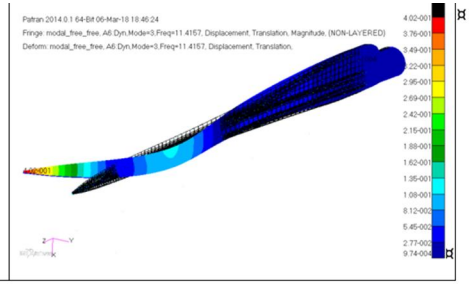
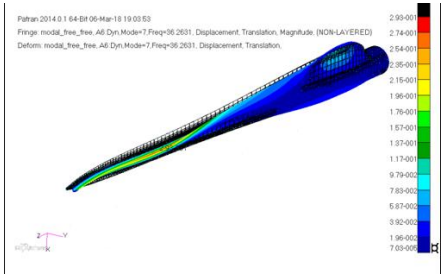


Object of investigation

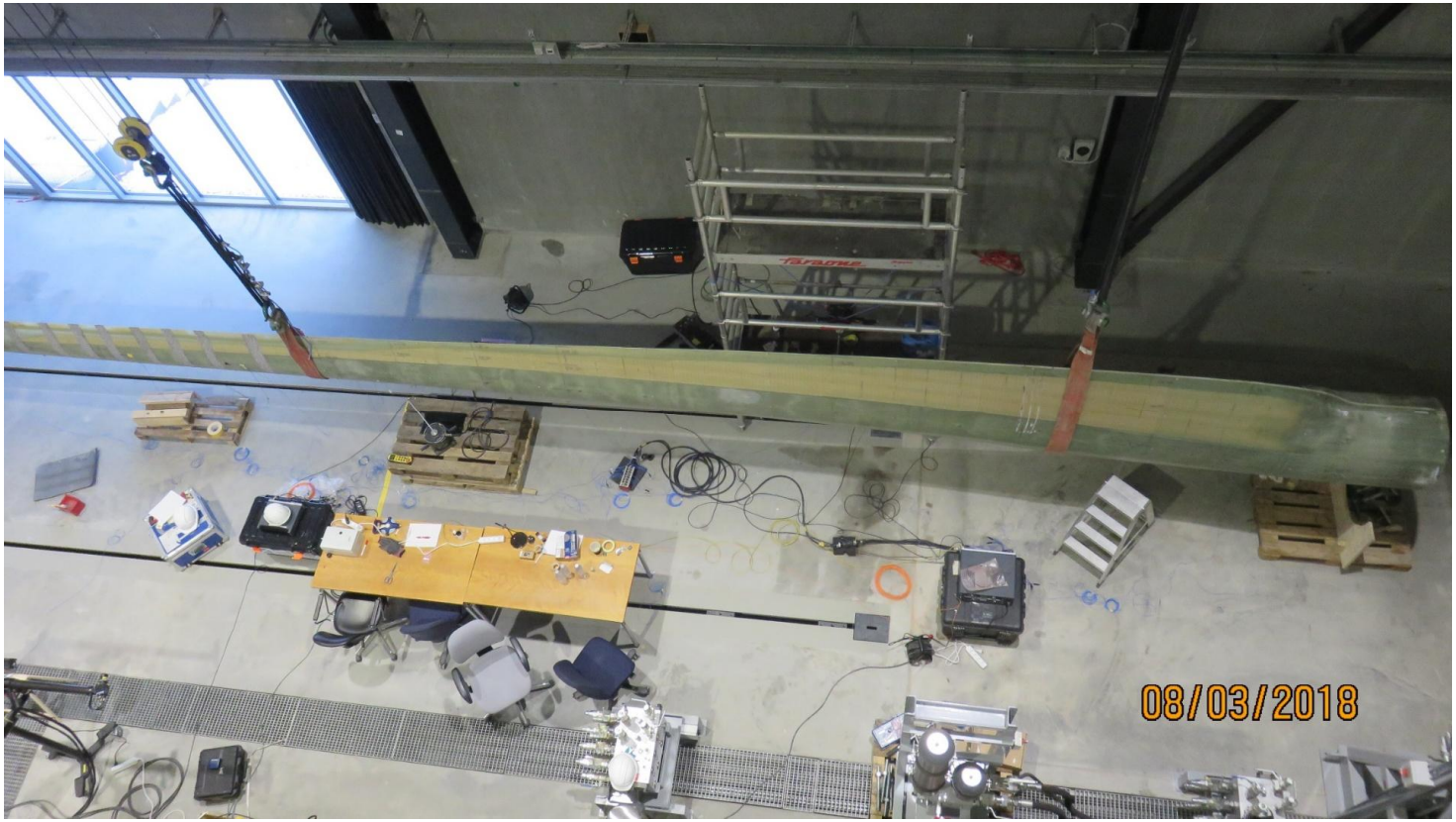
- FEM model of the blade with the measurement points



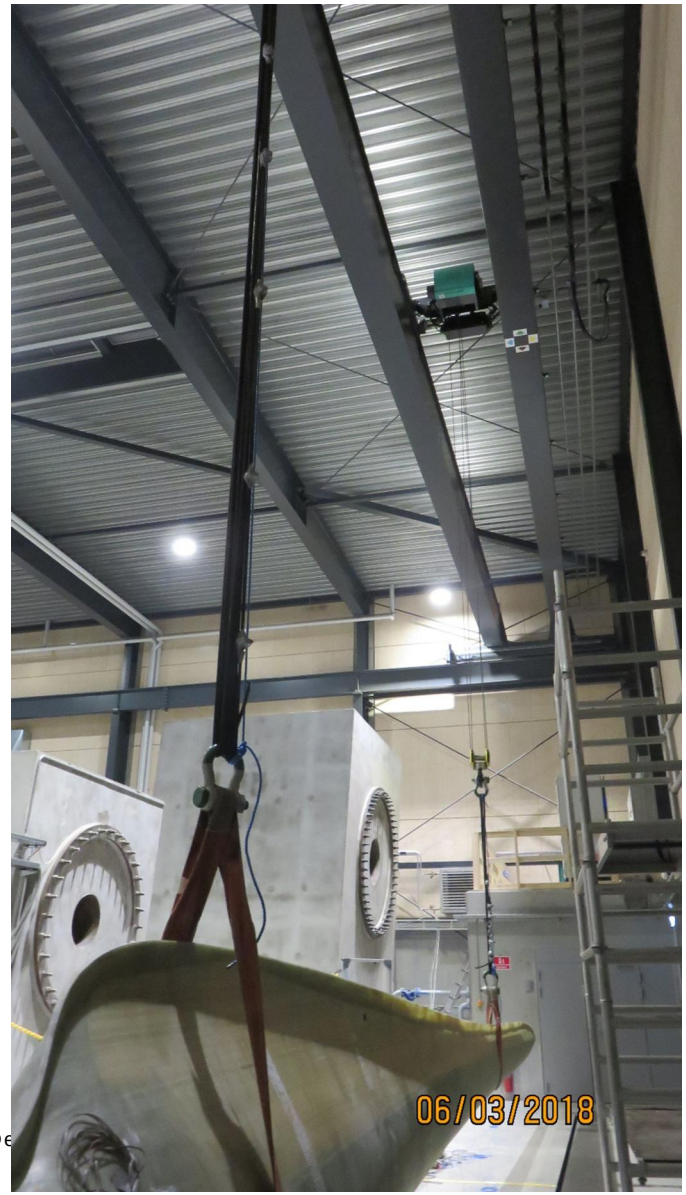
Modes from FEM model

Mode·[#]¤	Frequency·[Hz]¤	Mode,·numerical·model¤
1,¶ ¶ ····1st·flap·mode¤	4.15¤	
2,¶ ¶ ¶ ··1st·edge·mode¤	9.82¤	
3,¶ ¶ 2nd·flap·mode¤	11.42¤	
7,¶ ¶ 1tst·torsion· mode·¤	36.26¤	

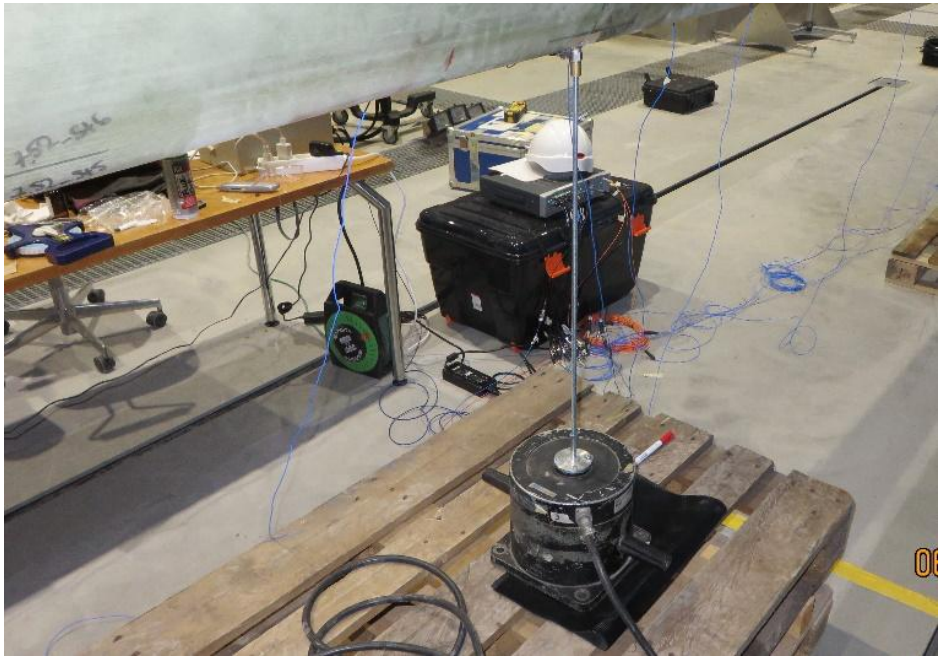
Test setup - overview



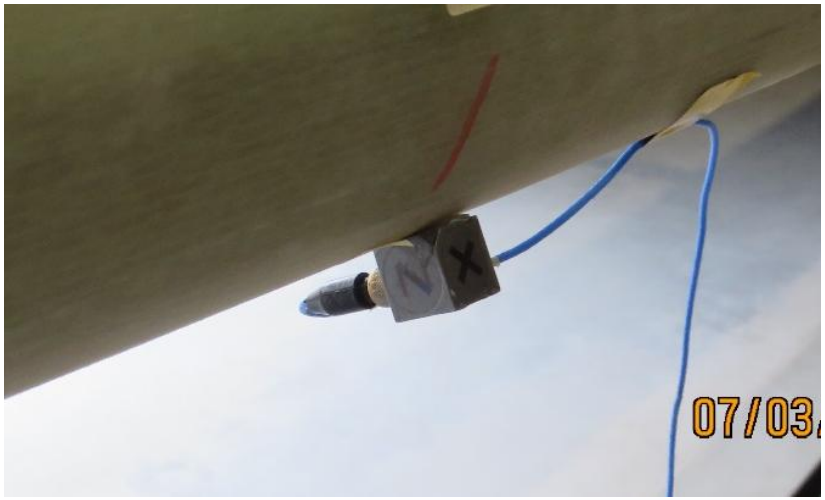
Test setup
free free support

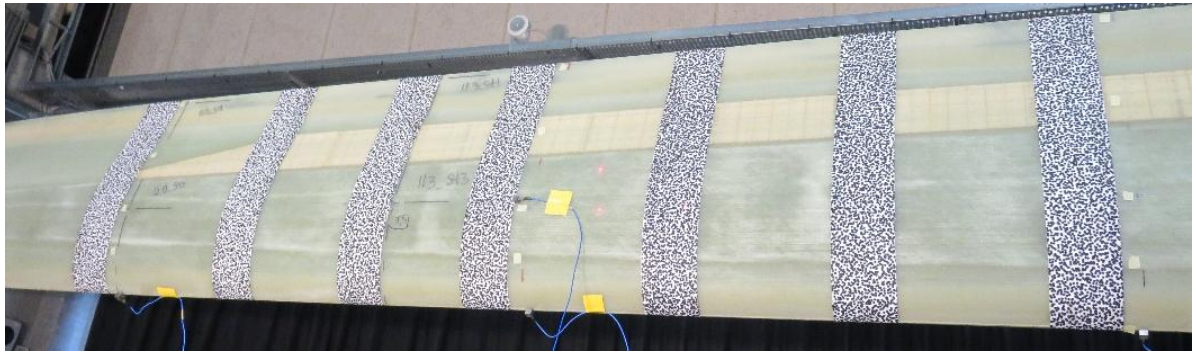


Test setup: Excitation



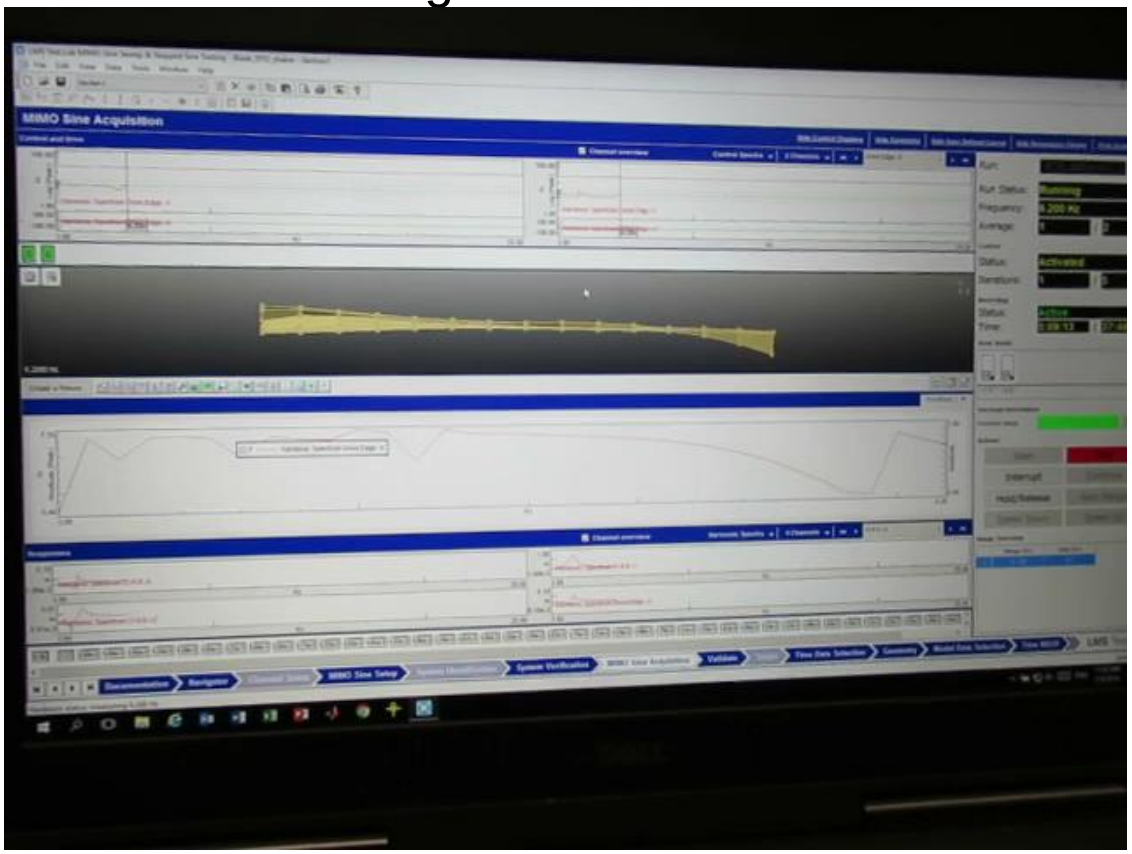
Test setup: Response



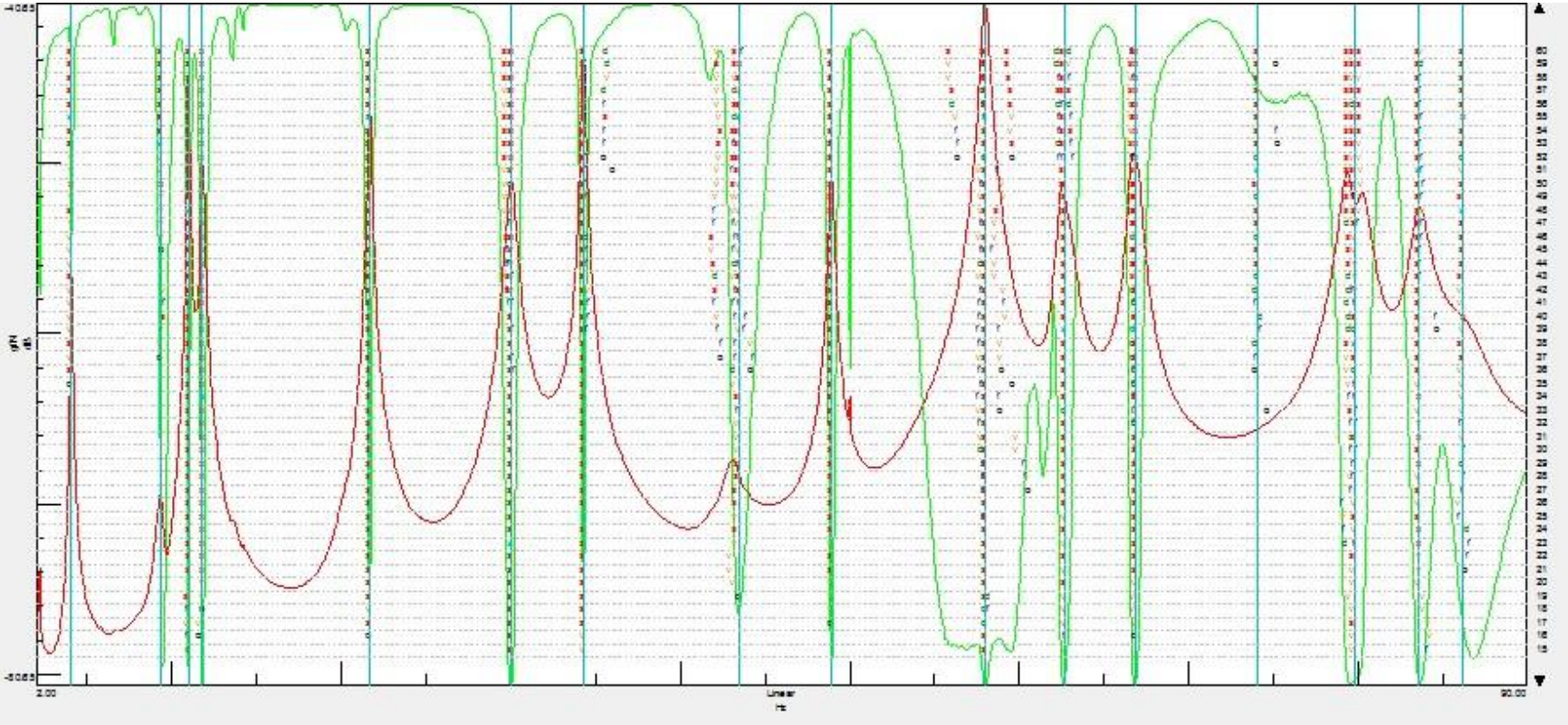


Measurement – software

Measurement - monitoring

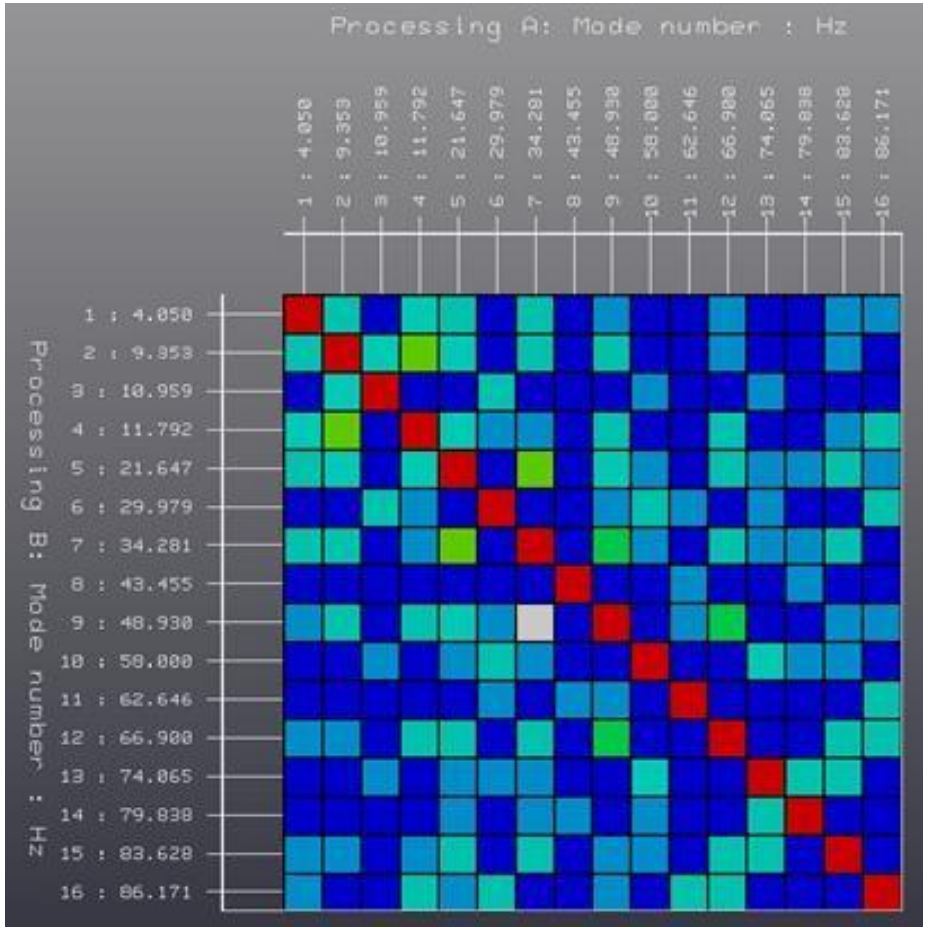


Stabilisation Diagram

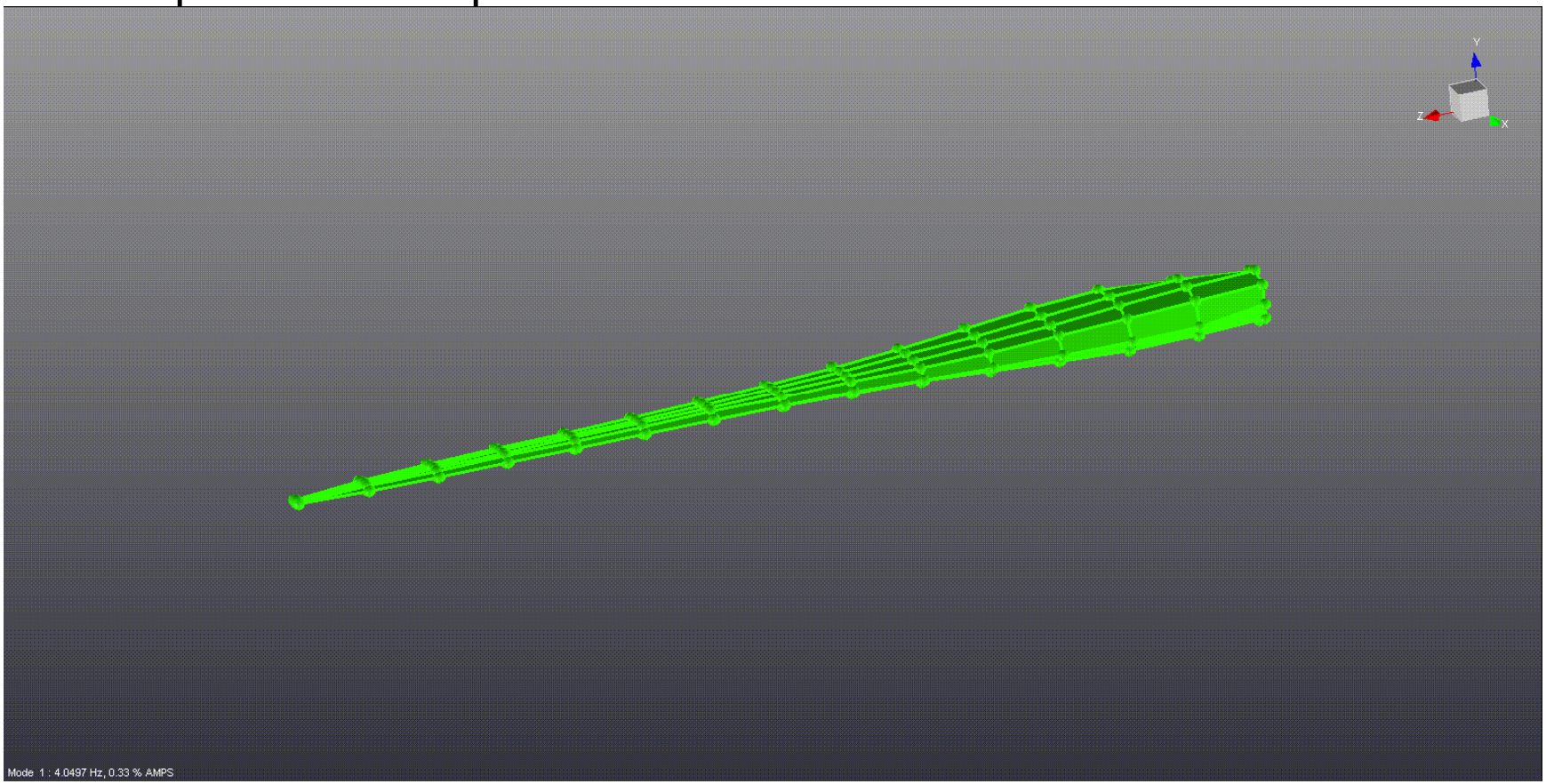


Mode frequencies, damping and Auto MAC

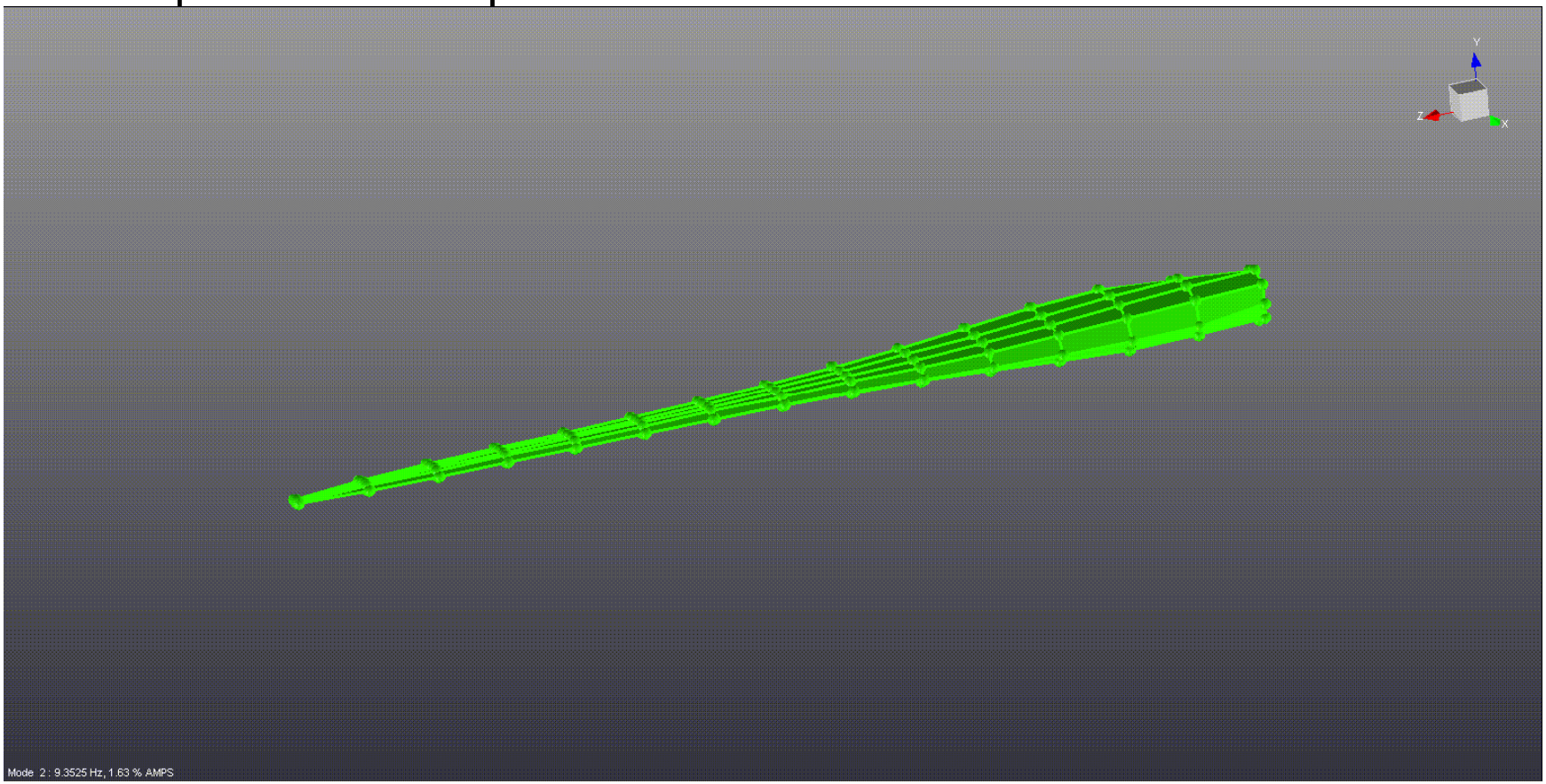
- Mode 1 : 4.050 Hz, 0.33 % AMPS
- Mode 2 : 9.353 Hz, 1.63 % AMPS
- Mode 3 : 10.959 Hz, 0.41 % AMPS
- Mode 4 : 11.792 Hz, 0.87 % AMPS
- Mode 5 : 21.647 Hz, 0.41 % AMPS
- Mode 6 : 29.979 Hz, 0.87 % AMPS
- Mode 7 : 34.281 Hz, 0.25 % AMPS
- Mode 8 : 43.455 Hz, 2.12 % AMPS
- Mode 9 : 48.930 Hz, 0.27 % AMPS



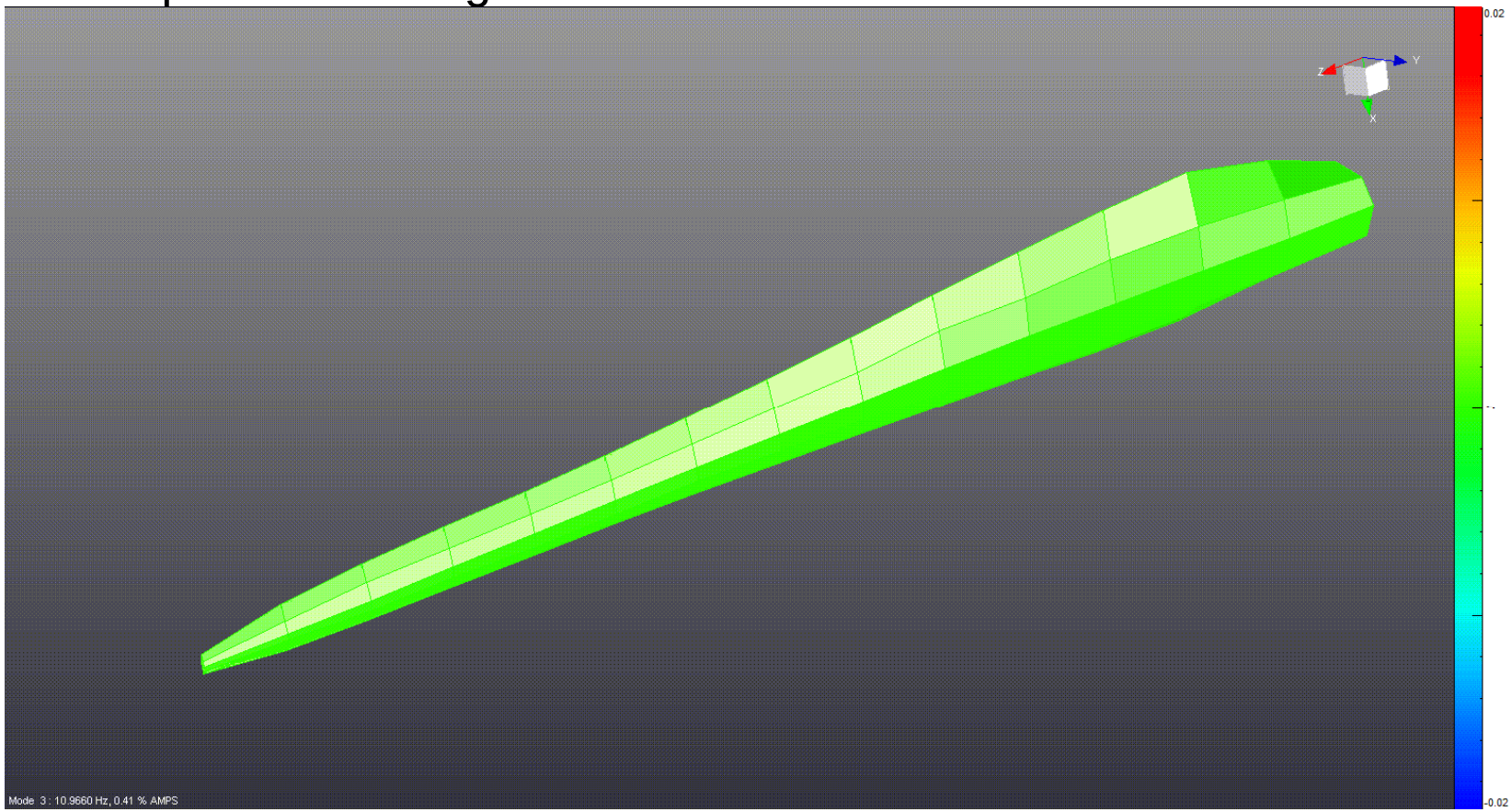
Mode shape – 1st flapwise



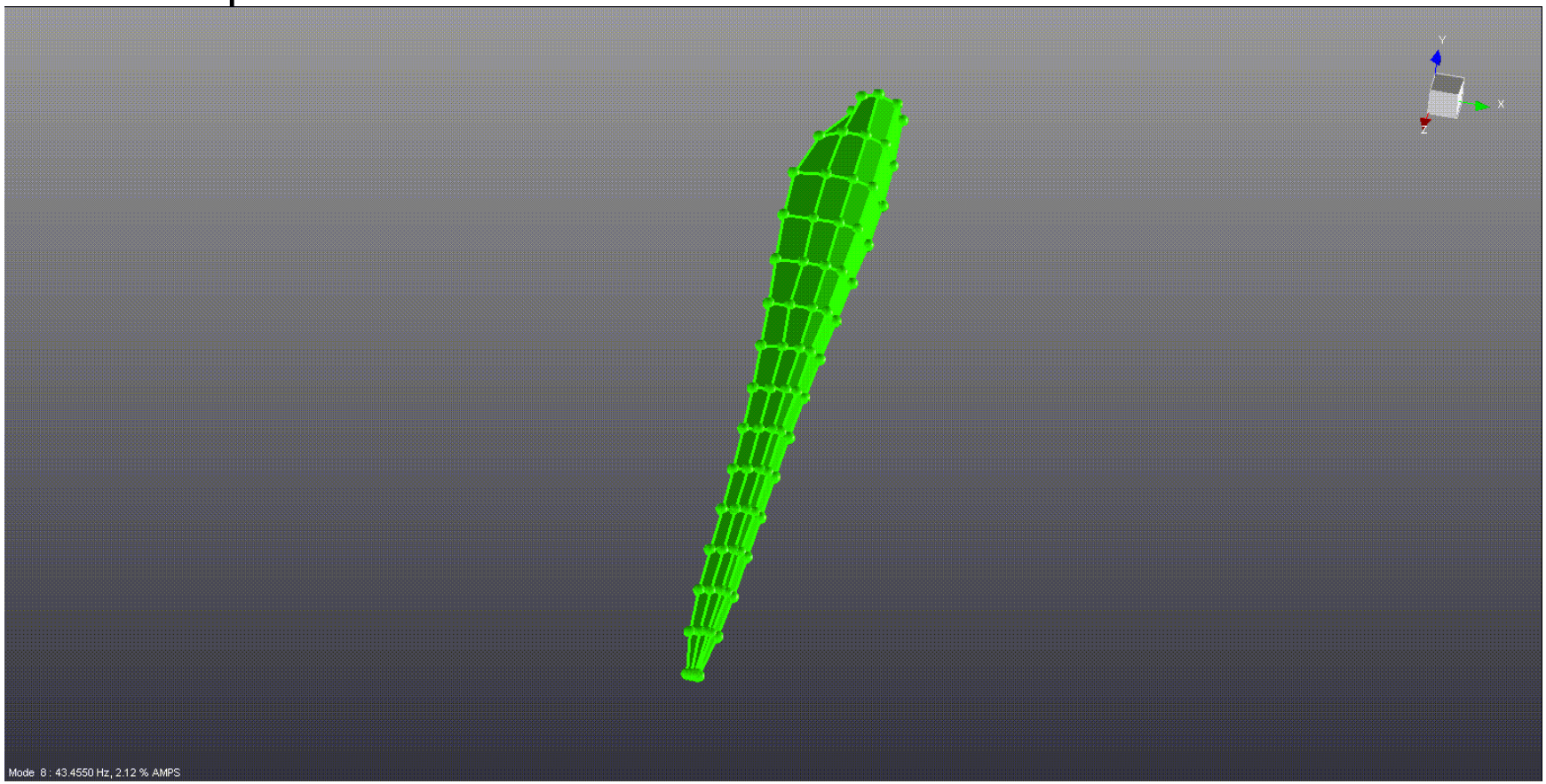
Mode shape – 2nd flapwise



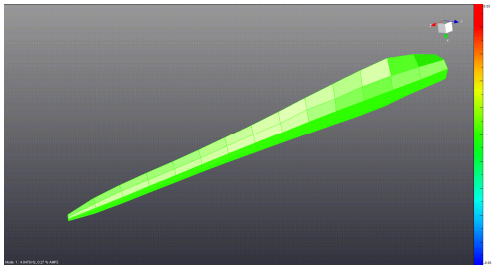
Mode shape – 1st edgewise



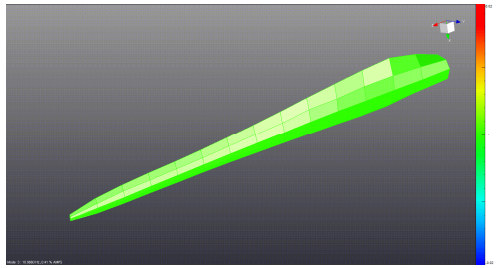
Mode shape – 1st torsion



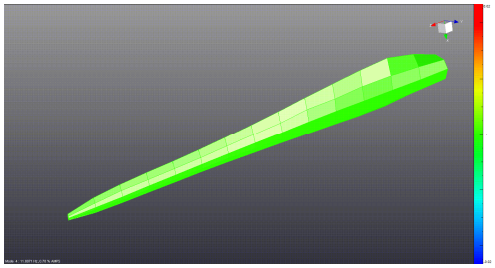
Results: Experimental Modal Analysis



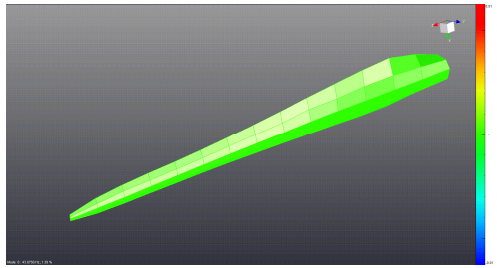
1st flap mode
4.05 Hz



1st edge mode
10.97 Hz



2nd flap mode
11.81 Hz

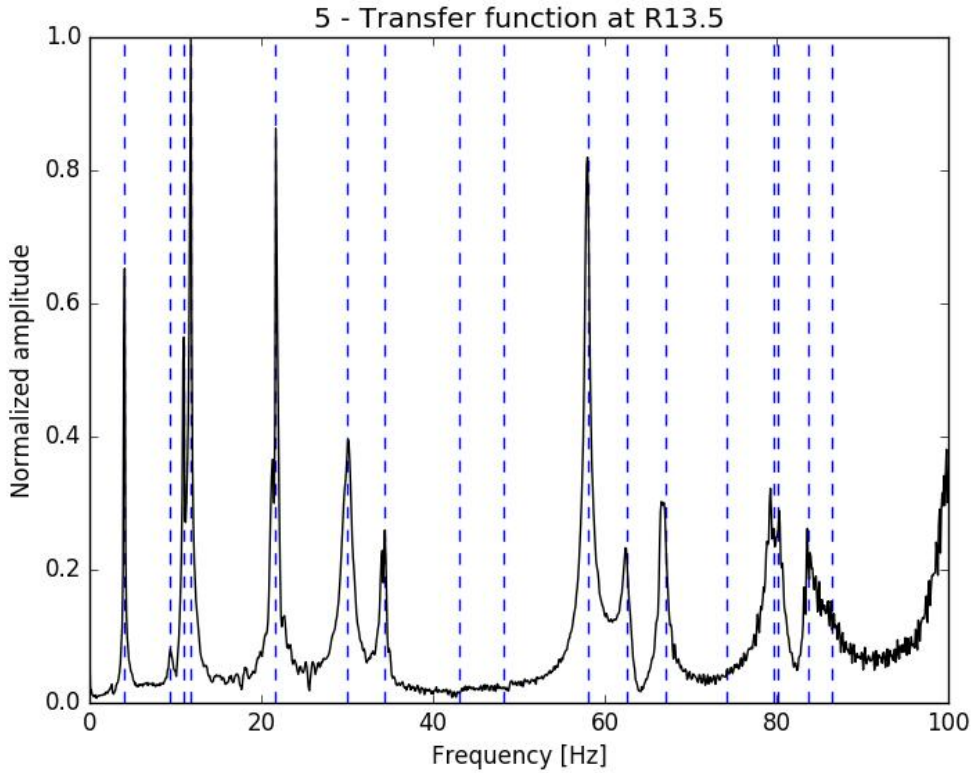


Torsion mode
43.08 Hz

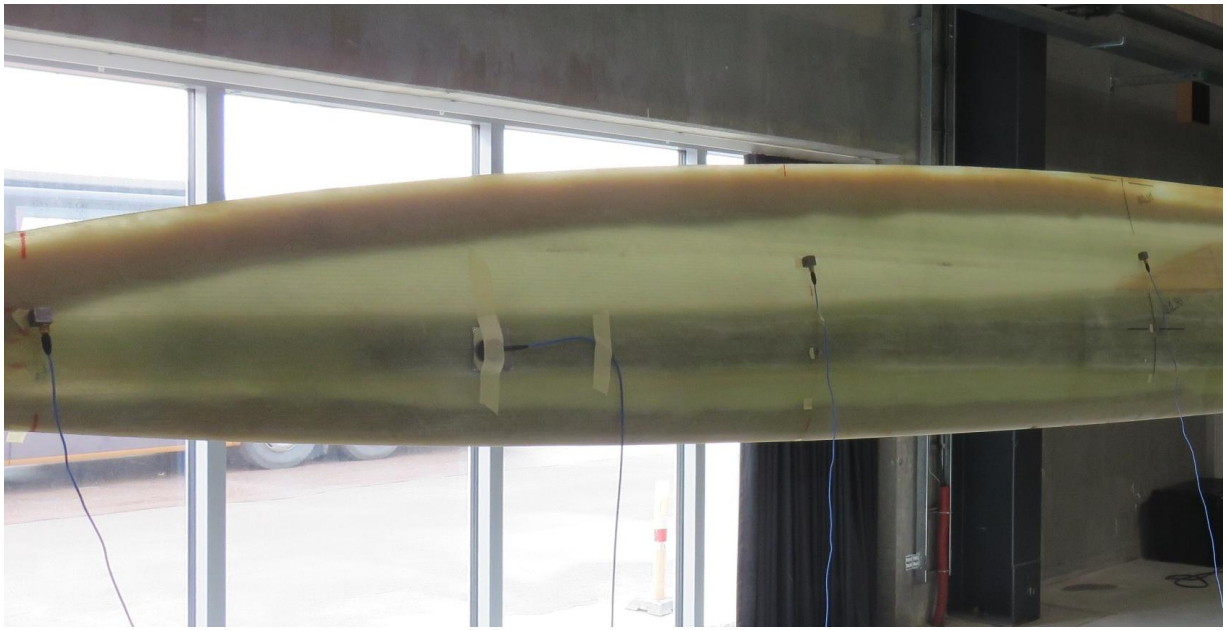
Results: comparison FE vs Experimental

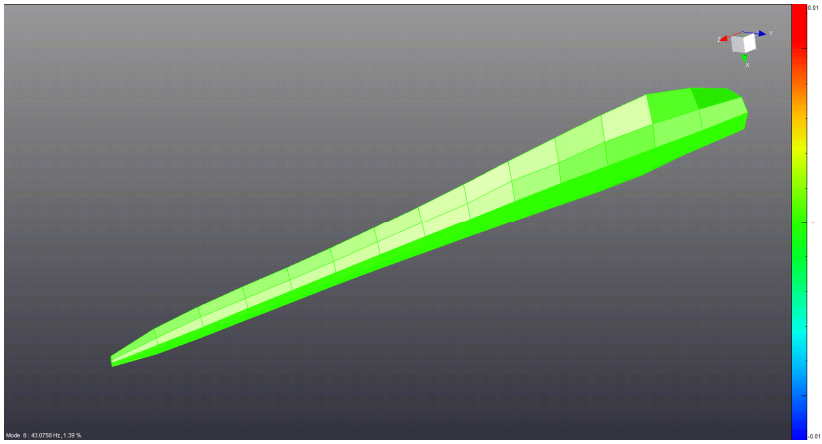
FE model	Experimental analysis	
Natural frequencies	Natural frequencies	Damping ratios
4.15 Hz	4.05 Hz	0.27%
9.82 Hz	10.97 Hz	0.41%
11.42 Hz	11.81 Hz	0.78%
36.26 Hz	43.08 Hz	1.39%

Results: CEKO optical accelerometer



Results: CEKO optical accelerometer





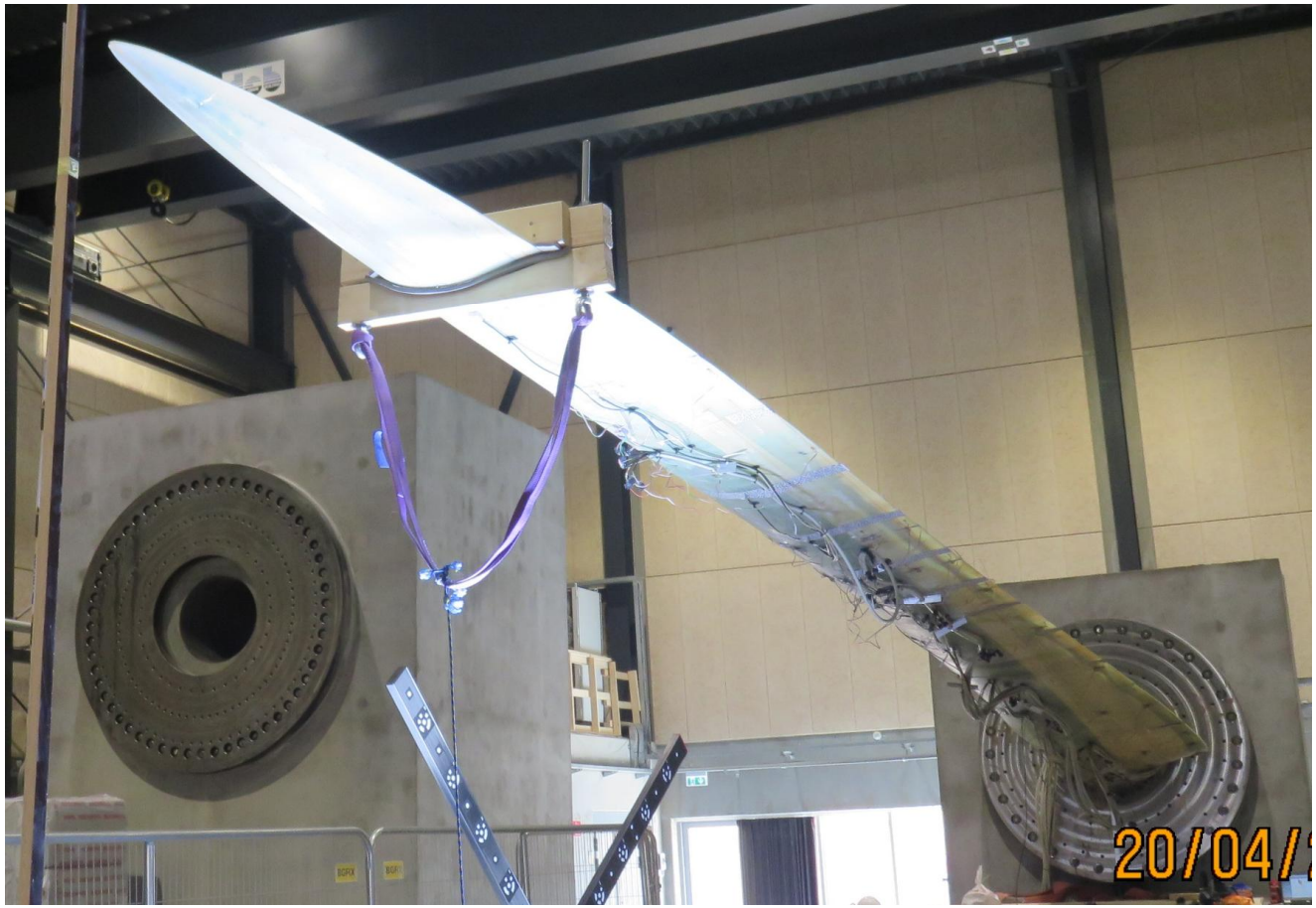
Conclusions:

- Different excitation techniques applied (impact, random, stepped)
- ICP and optical contact sensing principles used and assessed
- Modes are well separated
- All parameters of the modal model of the full scale blade estimated within 200 [Hz] bandwidth:
  - natural frequencies,
  - mode shapes
  - damping ratios
- Good consistency of the results from different methods and FE model

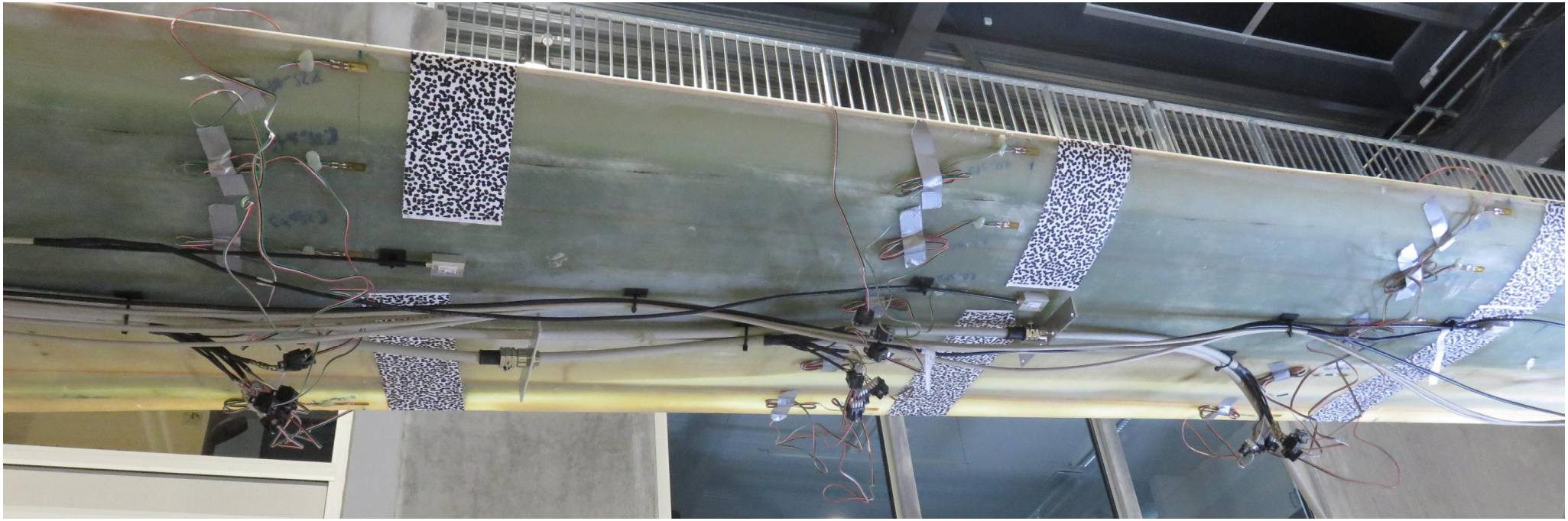
Future outlook:

- Investigate further the frequency difference for the Torsional mode
- Test-simulation correlation, model validation and updating,
- Uncertainty Quantification
- Test on the 2nd blade
- Pull and release, strain, output only modal analysis
- Dissemination:
  - ISMA, International Conference on Noise and Vibration Engineering
  - WindEurope Summit,
  - IMAC Conference & Exposition on Structural Dynamics.

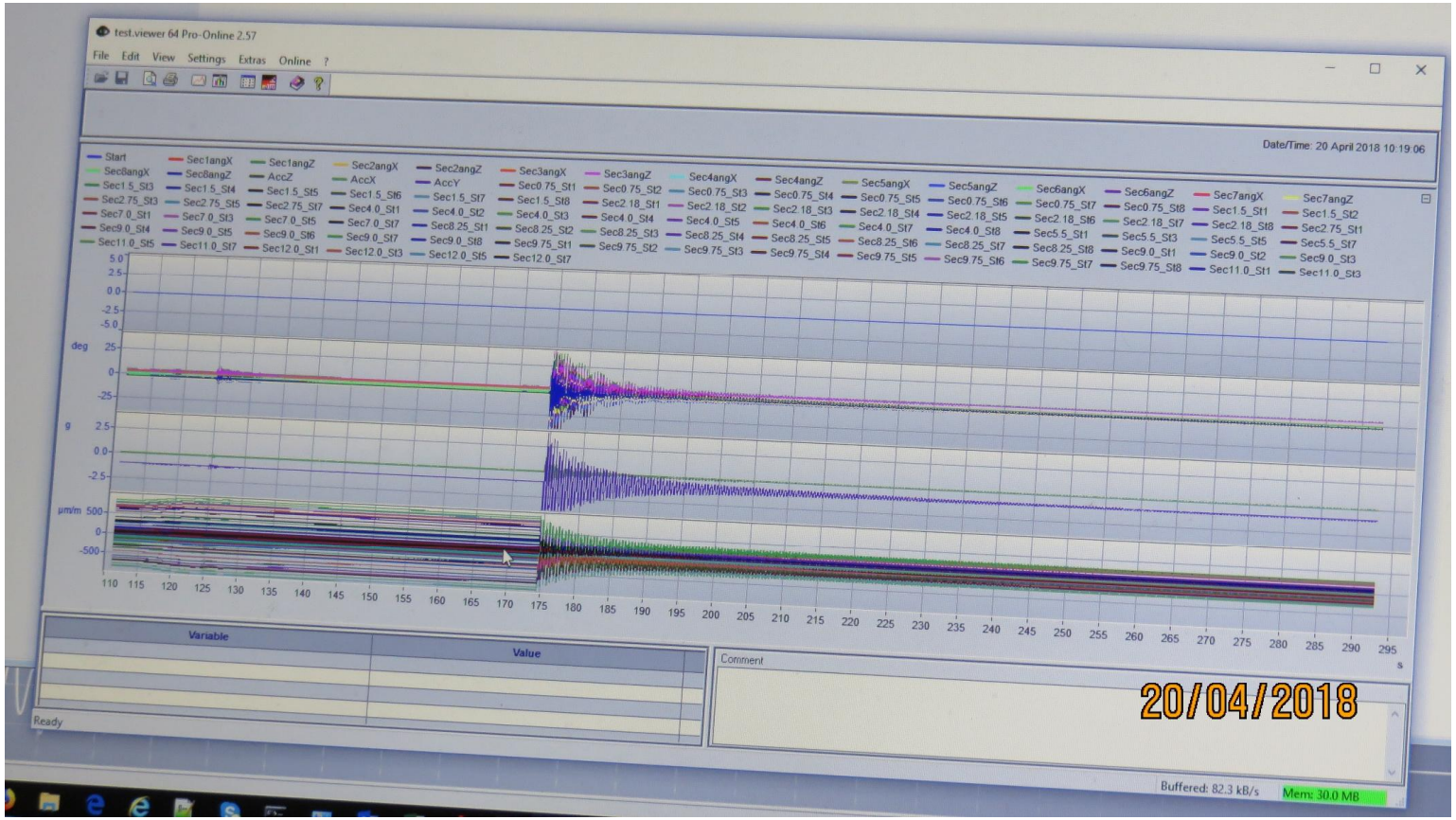
Pull and release free vibration test:



Pull and release test:



Pull and release test:



Pull and release test:

Differencies between the tests:

- Clamped – free support configuration
- Flapwise orientation
- Additional mass from cables and „saddle”
- Output only signals
- Stain gauges

Acknowledgements:

- Siemens Industry Software: Emilio Di Lorenzo, Simone Manzato, Bart Peeters
- CEKO Sensors: Kasper Reck-Nielsen
- DTU Wind Energy: Peter Berring, Federico Belloni, Sergei Semenov, Steen Hjelm Madsen, Kim Branner, Philipp Ulrich Haselbach

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