Acoustic Signal in Wind Turbine

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1 Experimental Setup and Parameters

The overall aim is to investigate how to detect faults in wind turbine blades through acoustic emission (AE) measurements. In lab experiments, we move the blade up and down and detect the sound it makes through analogue sensors. The blade in this experiment is 14.3 m long.

Four embedded faults are made during the construction of the blade and AE-sensors are placed around them, see Figures 2 and 3. The blade is then excited by an arm that moves it in two different directions at once: Flap-wise (bending along the narrow direction of the blade) and edgewise (bending along the wide direction of the blade). The total movement is perhaps best approximated by a figure eight. The frequency of the flap-wise movement matches an eigenfrequency of 2.305 Hz, which has a quite narrow band and therefore can be regarded as a constant. Note that this is of course a resonance that is avoided in the real world, because the large amount of movement puts a bigger stress on the blade. (If we didn't use this frequency in the lab, it would take forever to test the growth of faults.) As the blade is alternating between C-shaped and figure of 8 movements, the edgewise motion has twice the frequency of the flap-wise motion.

The conversion from analogue to digital is a bottleneck, so the full signal is not saved. Instead, a number of waveform parameters are saved, see Table 1 for a list of these and Figure 1 for an illustration of them.

The wave packets are strongly dampened, so hardly any acoustic events reach more than the two adjacent sensors. We use a value for the speed of sound along the blade of around 2 km/s,

Variable	Description	Unit
Rise	Time between first crossing of threshold and the maximum amplitude.	Microseconds (μs)
Amplitude	Maximum amplitude of wave packet.	Decibels (dB)
Count	Number of threshold crossings.	Number
Duration	Time between first and last threshold crossings.	Microseconds (μs)
Average Frequency	Count divided by duration	Kilohertz (kHz)
MARSE Energy	Approximation of the energy by looking at the area underneath the envelope. More robust than the actual energy.	-
Abs Energy	Estimate of the true energy of the wave packet through integration over the squared waveform.	Attojoules (aJ)

Table 1: Description of the waveform parameters captured by the AE-sensors.

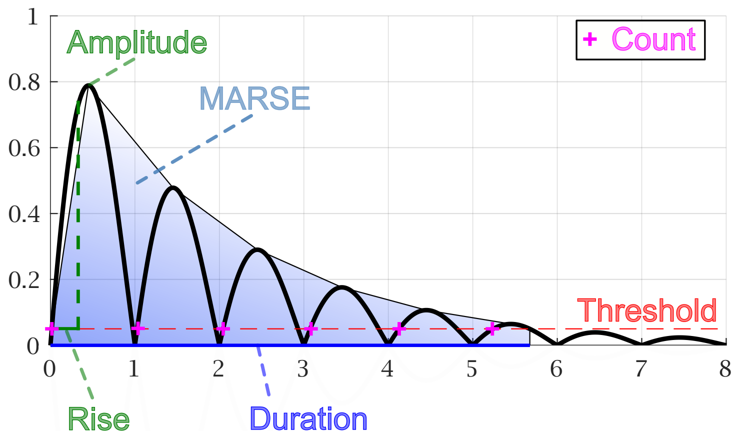

Figure 1: Illustration of some of the waveform parameters captured by the AE-sensors along with the threshold for measurement.

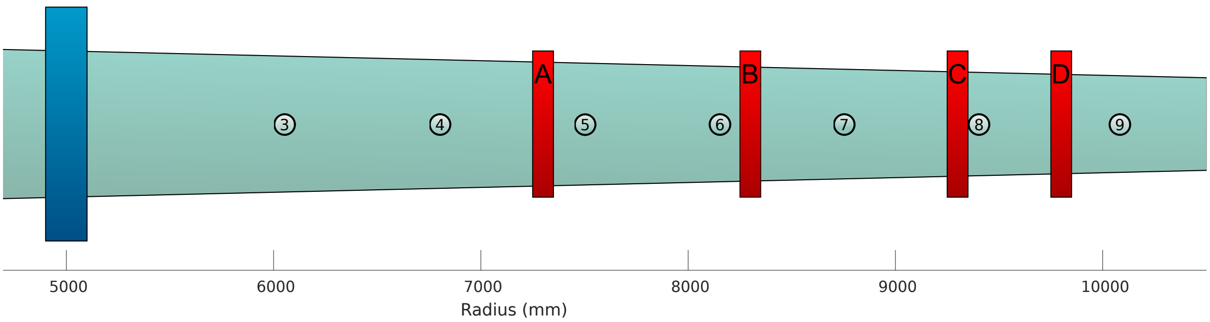

Figure 2: Illustration of the embedded faults (red bars) and sensors (circles). The numbers denote the channels (with CH1 and CH2 at the root of the blade outside the picture), and the red smaller blocks denote the wrinkles. The large blue block is the attachment of the exciter arm.

but unfortunately the actual speed of sound is anisotropic (and most likely non-uniform).

2 Smoking Guns and Open Questions

Inspecting an active wind turbine is a costly affair, so we would like to limit the number of times we have to actually look at the blade. The overall goal of the setup is therefore to find signatures of the faults that can be used to identify them in a real-world setting. In the literature, see e.g. [1], high energy events in certain frequency bands have been associated with particular types of damage. We see a similar behaviour in our experiment, see Figure 4, but there are aspects of this plot that are still poorly understood.

A number of questions stand out:

- We suspect that the double band in Figure 4 comes from the blade being moved in two directions at once, so different modes are excited. We attempt to confirm this by looking at the calibration period where the blade is moved in one direction at a time, see Figure 5. However, we only see a band in the flap-wise movement, most likely because we cannot apply the same force to the edgewise movement. When they move together, some

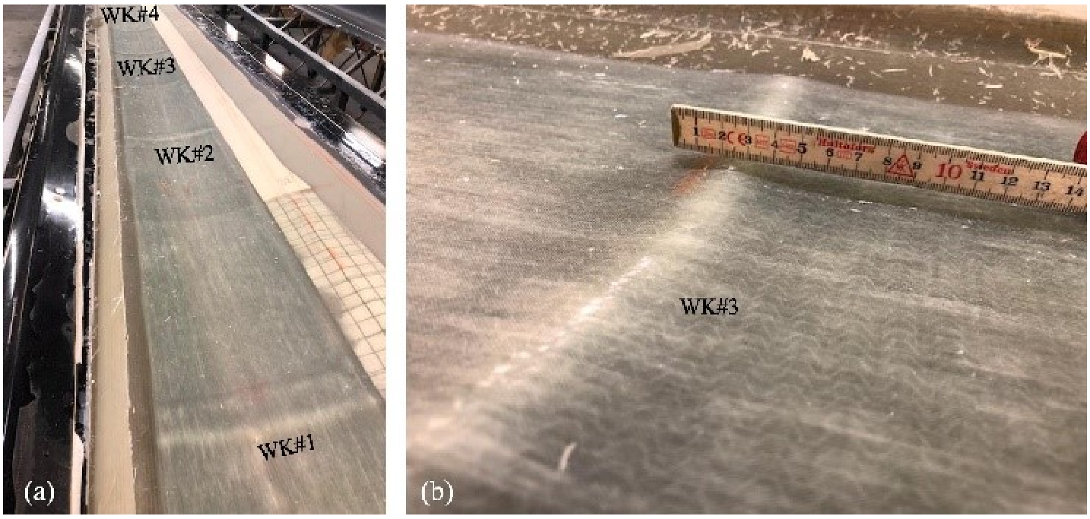

Figure 3: Photograph of the blade (a) alongside a zoom-in on Wrinkle 3 (b).

interplay happens and both bands appear. Annoyingly, the single band from the flap-wise calibration does not align with either of the two biaxial bands. This may be due to level repulsion, but we have so far not been able to confirm this.

Question: Does the double band in Figure 4 come from the biaxial movement? Can the presence of a band be used as indicator of a fault, or is it an artefact of the way the blade is excited?

- We do not understand why the bands in Figure 4 increase in frequency over time. The wrinkles are growing in size, which would suggest growing wavelength and thus decreasing frequency. If they are the consequence of a new type of damage appearing, they should just appear discontinuously. We cannot explain why they appear continuously from the bottom.

  Question: Can the increase in frequency in Figure 4 be reproduced in a model with increasing wrinkle width?

We are therefore very interested in what can be divulged from a simulation study of this blade or similar analysis. First of all, simply understanding the null-model (i.e. no faults) would be a step in the right direction. If this turns out to be trivial, investigating the effect of adding wrinkles be the next step.

Precise information about the shape of the wrinkles are unfortunately not available, but we expect that approximations following the width guide in Table 2 would go a long way. We would like to be sure that the high energy around 40 kHz is indeed a signal from the wrinkles, and not an artefact of the experiment setup where the blade is heavily excited. In other words, we want to know if we should expect to see a similar signature when we go out in the real world, where we do not work at a blade resonance frequency. This is especially critical, because we do not observe the same frequency/energy signature in an experiment with a 31 m blade. The type of fault is also different there, so it might only be due to the type of fault, but investigating the effect of blade length would also greatly be appreciated.

	check	**start**	**stop**	**TestBlock**		**Wrinkle Width [mm] at middle after test block**			
Day	Time					A	B	C	D
24-mar	15h13		16h50	1		56	52		55
25-mar	10h20	10h42	11h56	2		62	57		56
	12h45	12h45	14h15	3		70	60		56
	16h17	16h59	18h05	4		75	61		59
26-mar	9h10	9h28	10h34	5		80	61		59
	10h56	11h12	12h26	6		82	65		60
	13h04	13h19	14h33	7		85	68		61
	14h54	15h07	16h21	8		88	70		62
29-mar	10h25	10h43	11h59	9		90	72		63
	12h34	12h50	14h07	10		93	74		66
	14h46	15h02	16h11	11		96	76		70
30-mar	11h28	12h39	13h44	12		105	81		75
	15h30	15h47	16h45	13		115	85		79
06-apr	11h23	11h37	12h34	14		145	100		85
	14h10	14h25	15h02-05	15		175	110		90

Table 2: Test log along with measurements of wrinkle sizes. Note that there are no data available for Wrinkle C, because it is behind a DIC measurement layer.

3 References

[1] R. A. A. Lima, R. Tao, A. Bernasconi, M. Carboni, S. Teixeira de Freitas (2023), Submitted for publication in Composites Part B.

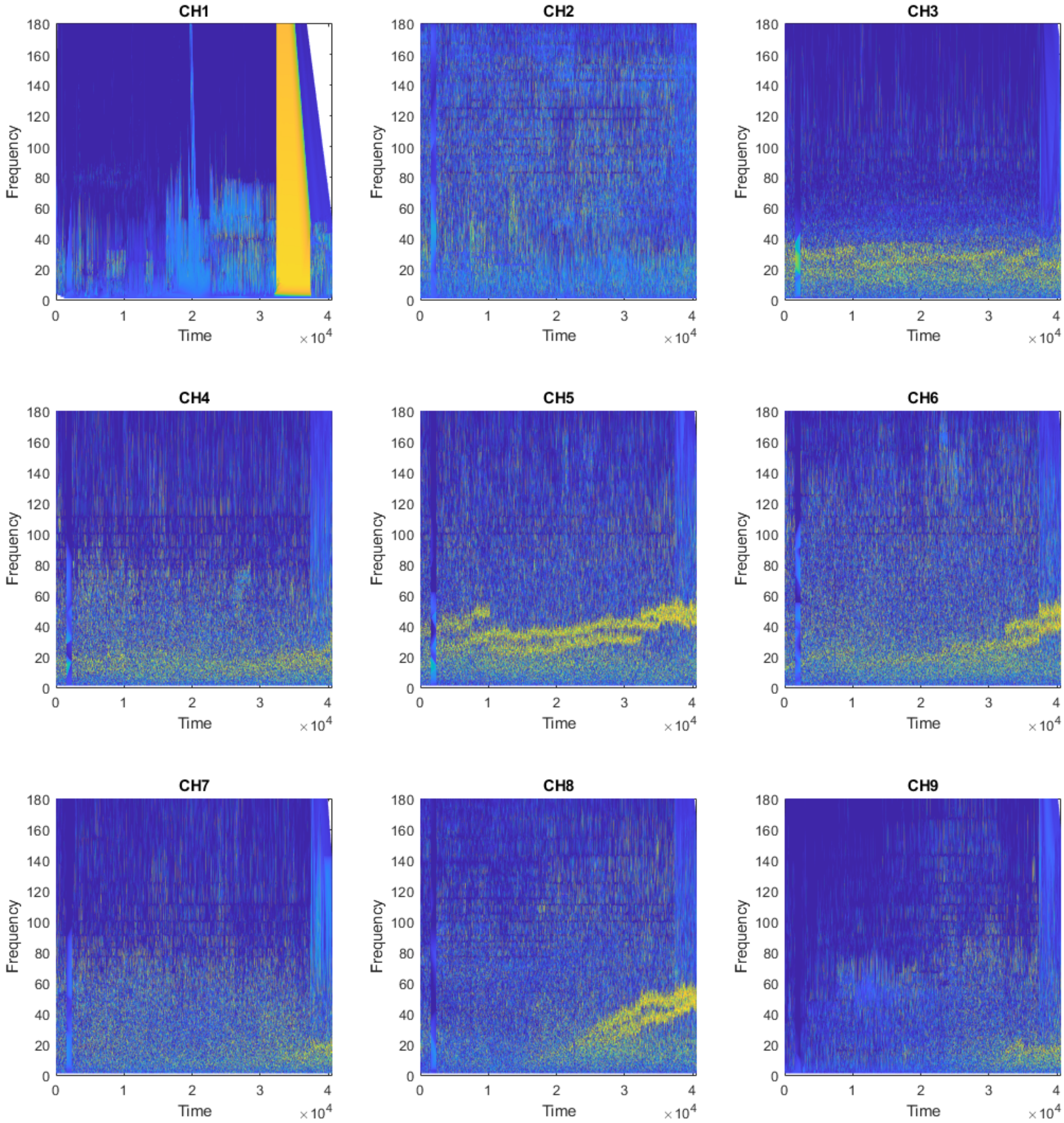

Figure 4: A plot of time (x-axis, seconds) versus frequency (y-axis, kHz) versus MARSE energy (colour axis, log scale, blue-yellow) for the full experiment. The yellow bands visible around 40 kHz are assumed to be related to the faults. The interpretation seems to be: CH5 is very close to Wrinkle A and thus has a clear signal. The other wrinkles grow over time and create a signal too. CH7 is right between two wrinkles, and the signal is too dampened to really reach all the way.

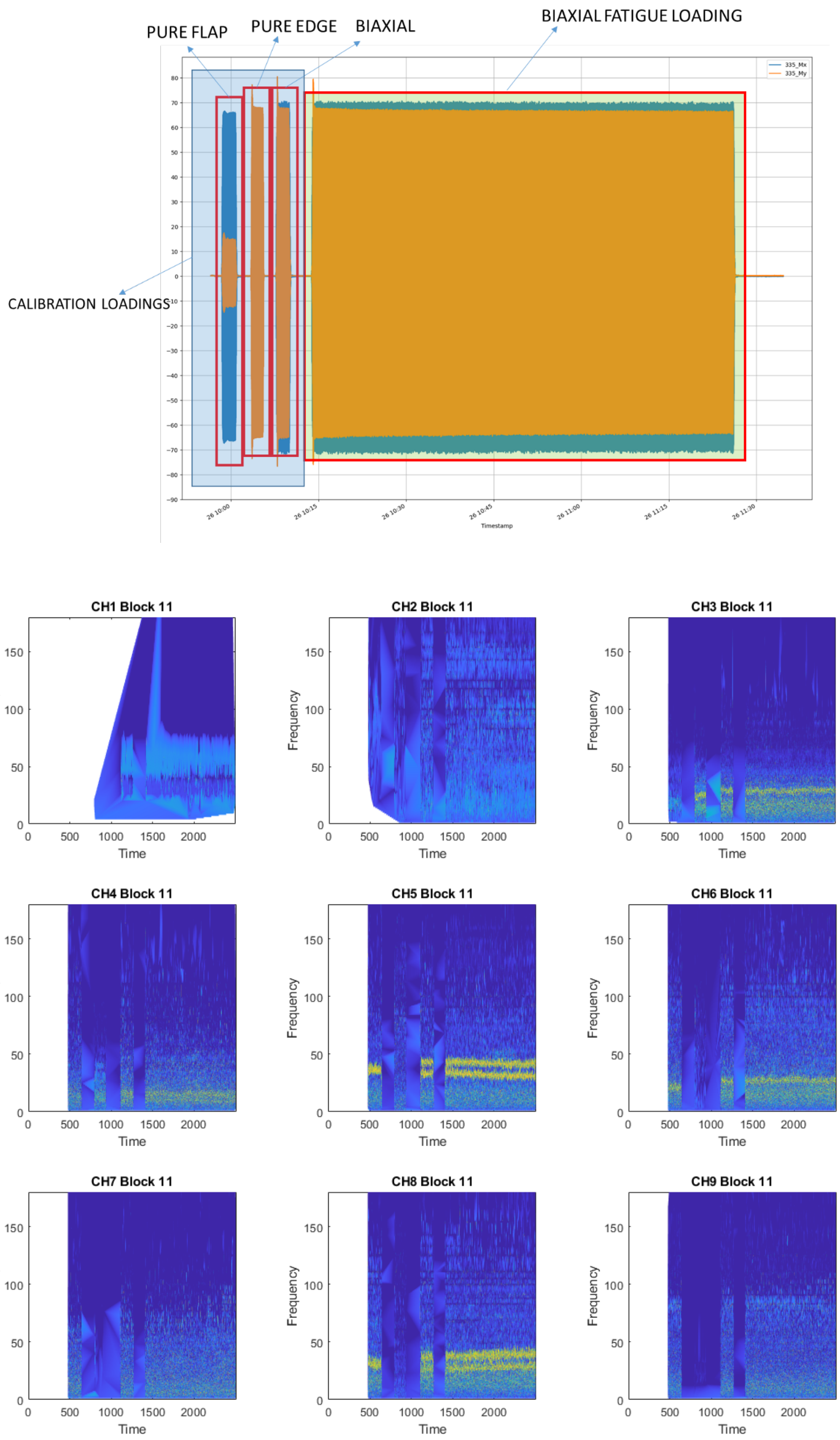

Figure 5: The calibration period of the experiment, where the flap, edge, and biaxial loadings are visible. **Top:** Plot of calibration period. Note how there are periods with either direction on their own before the biaxial experiment. **Bottom:** A plot of time (x-axis, seconds) versus frequency (y-axis, kHz) versus MARSE energy (colour axis, log scale, blue-yellow) for the calibration period. The colour is interpolated, so the time between the different calibrations appear as almost uniform blue. Note how there is only one band in the flap-wise, no band in the edgewise, and two in the biaxial movement. We suspect that this is due to the weaker pull in the edgewise direction, which is only enough to excite the bands if there is interaction between the two directions of motion.