Fiber Bragg Grating Sensors for Continuous Condition Monitoring of Wind Turbine Drivetrain Components

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Policy Power People

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Introduction

- Wind Turbines (WTs) are widely adopted as a source of green energy
- Maintenance and operation costs are high, nearly 20-25% of total revenue expenditure [1]
- Half of failures with most downtime stem from mechanical components
- Cost of a new gearbox: R3.7 million [2]
- Maintenance of 3 MW WT: R2.4 million annually [3]

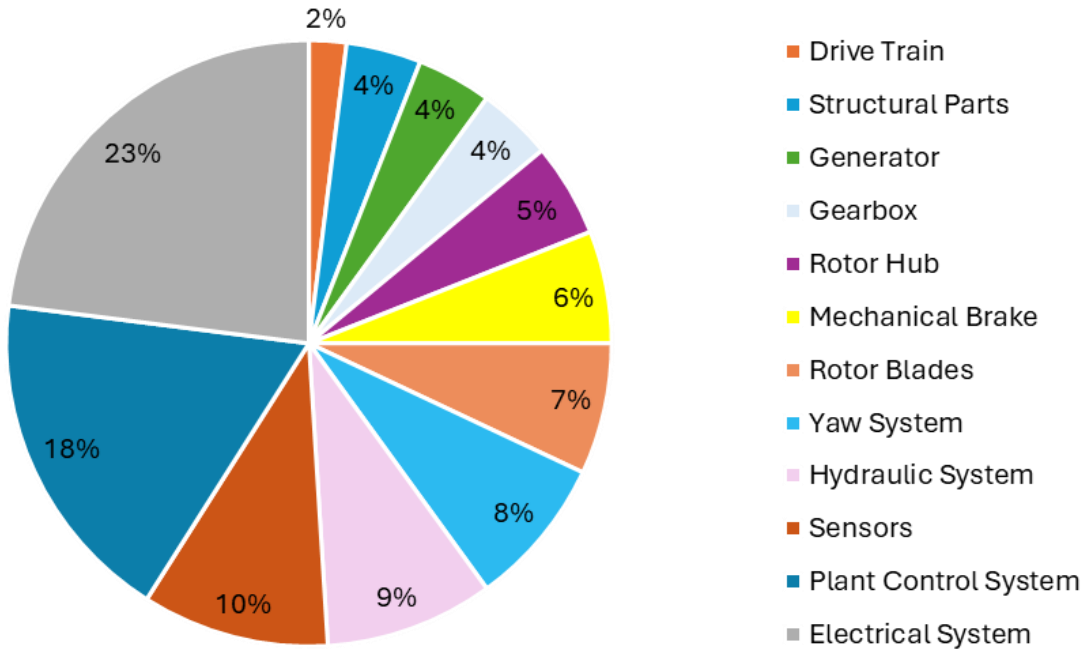


Figure 1: Percentage of total downtime by component [4]

Introduction

Why drivetrain condition monitoring matters

From scheduled maintenance toward earlier, condition-based intervention

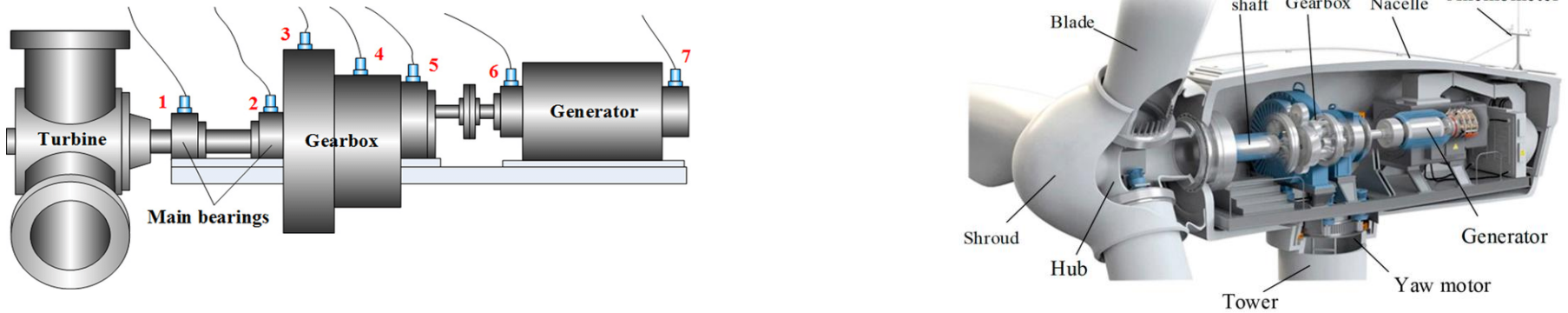


Figure 2: Components of a wind turbine drivetrain (left) visualized [5] and (right) in a wind turbine [6]

10–30%
reported share of onshore wind O&M costs [7]

25–50%
reported share of offshore wind O&M costs [8]

~15.5 days
reported repair downtime for some drivetrain/shaft equipment [9]

Research question

Can a compact point fibre-optic sensor recover meaningful vibration signatures from a wind-turbine drivetrain?

Motivation: reduce unplanned downtime and strengthen predictive-maintenance capability.

Introduction

What are Point Fibre Optic Sensors?

- Point fibre-optic sensors measure strain or temperature at a specific location along the fibre. Fibre Bragg Gratings (FBGs) being one of the most widely used examples.
- Reflect specific wavelength of light (Bragg wavelength), governed by the Bragg equation:

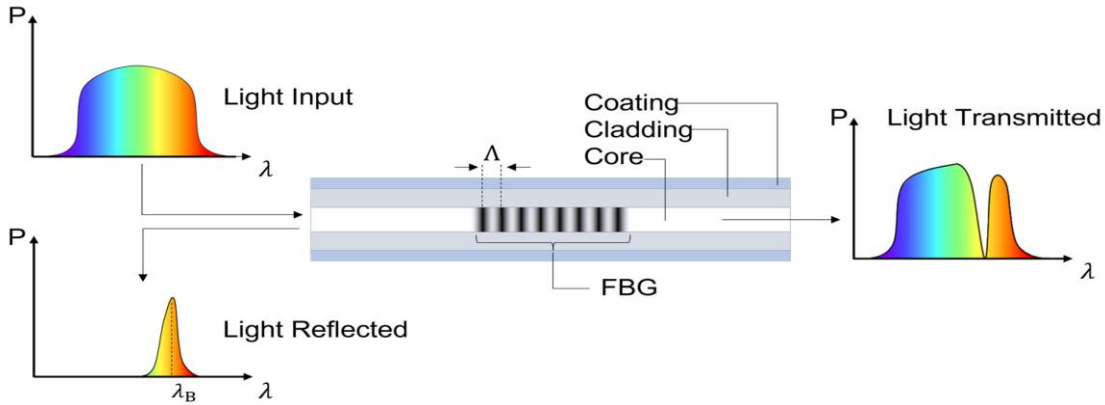


Figure 3: Functioning principles of an FBG [10]

- FBGs innately sensitive to temperature and strain – Bragg wavelength can be a "proxy".

$$\Delta\lambda_B = \lambda_B[(1 - p_e)\Delta\varepsilon + (\alpha + \xi)\Delta T]$$

STRAIN ← → TEMPERATURE

Introduction

Why use Fibre Bragg Gratings?

A compact optical route to strain and vibration monitoring

Conventional monitoring

- Accelerometers and strain gauges are established tools
- Rotating machinery can complicate cabling and sensor placement
- Harsh environments and multi-point monitoring increase system complexity

FBG opportunity

- Small, lightweight and passive sensing element
- Immune to electromagnetic interference
- Multiple gratings can be multiplexed along one fibre
- Sensitive to mechanical strain through Bragg-wavelength shift
- Demonstrated use for wind turbine tower and blade monitoring



Figure 4: FBG sensors using for temperature and radiation sensing at CERN

Gap: drivetrain applications remain comparatively less explored

Methodology

Manufacturing and Calibration

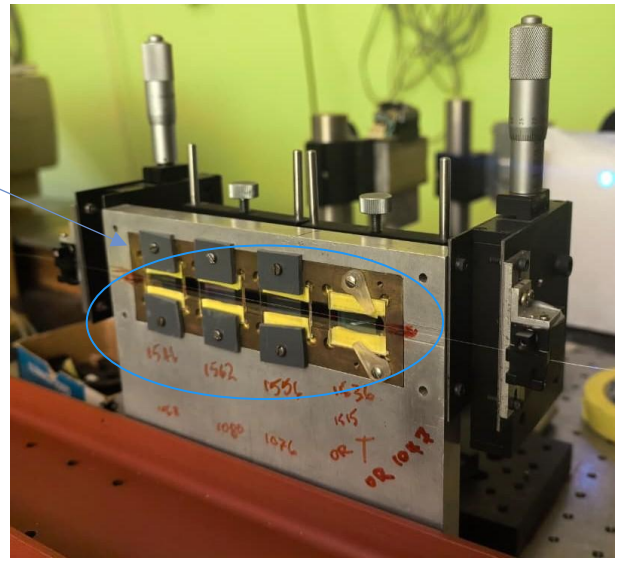
- FBGs produced in-house at UJ LOCALLY
- Written on Boron-doped silica (photosensitive for UV laser)
- Controlled strain instrumentation
- FBG strained by known amount and wavelength shift recorded

(a)



(b)

FBG formed here



(c)

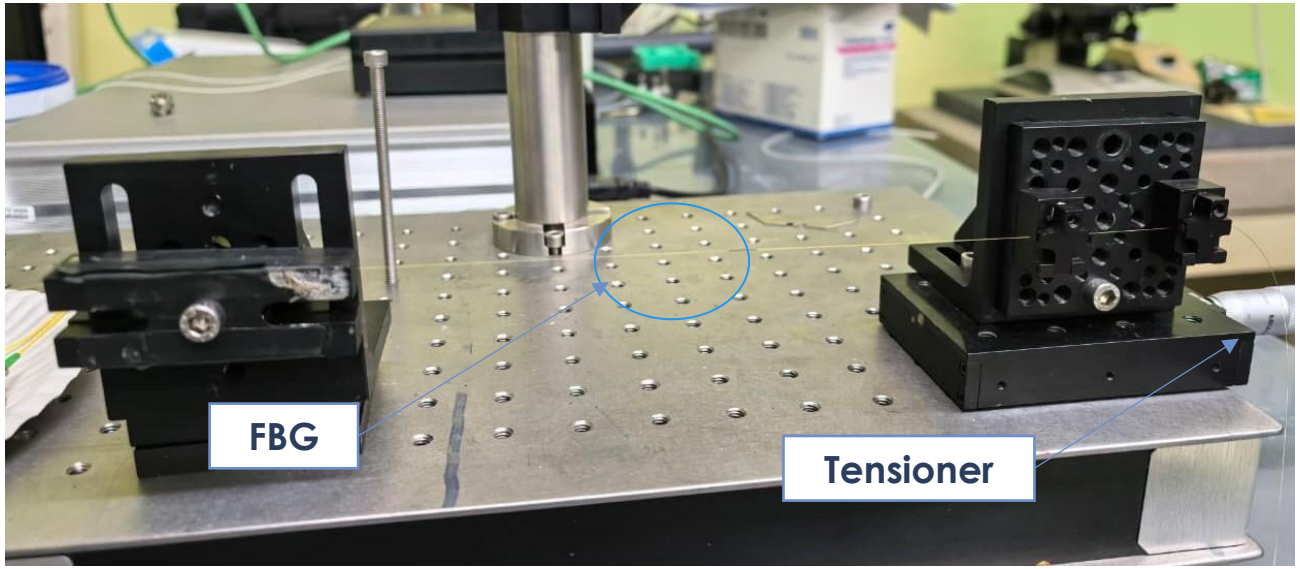


Figure 4: (a) Quanta-Ray UltraViolet Laser; (b) Phasemask to print FBG; (c) Strain calibration setup

Methodology

Manufacturing and Calibration

- Strain calibration produces sensitivity of 1.074pm/$\mu\varepsilon$
- Follows theoretical expectation for fibre composition
- Monitored wavelength shift can now be converted to strain

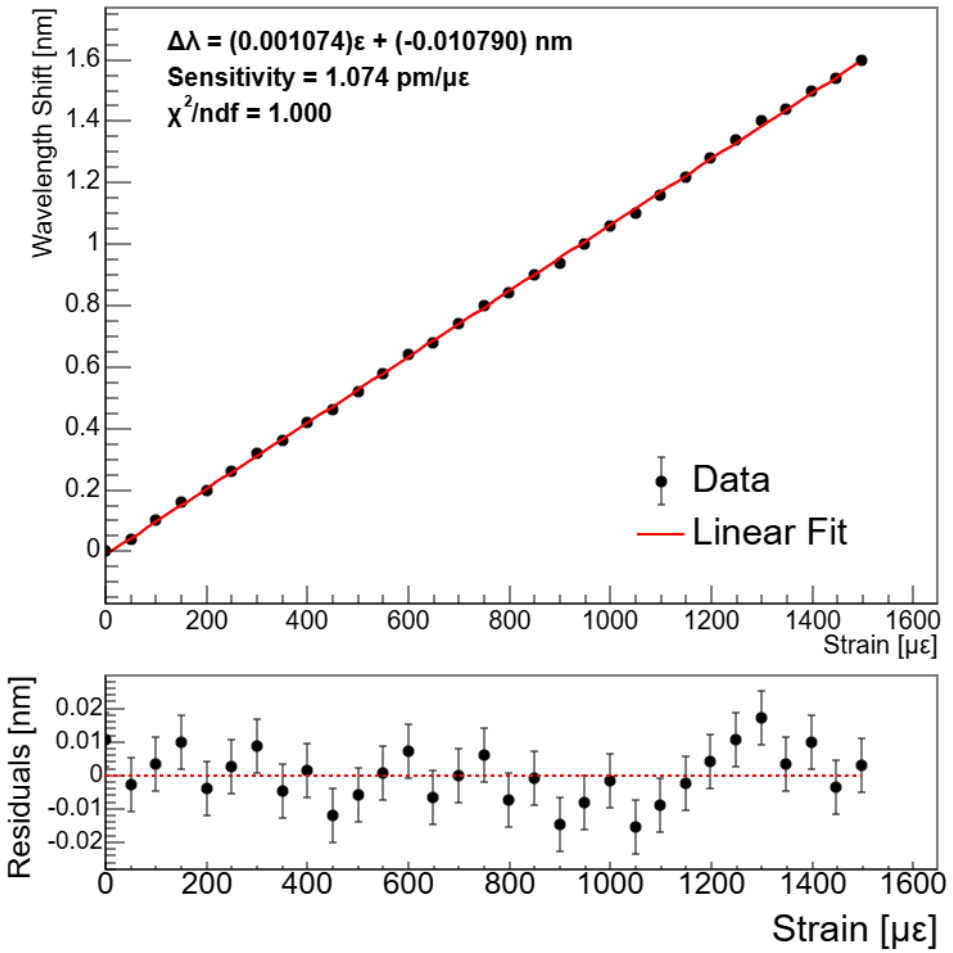


Figure 5: FBG strain calibration plot

Methodology

Setup and Acquisition

- Previously used test-rig designed for torsional vibration used
- Torsional vibration was measured using encoder disks stemming from the gearbox at 610 Hz []
- Accelerometer measurements also showed vibration at running speed
- Two speeds were used: Slow 66 rpm (1.1 Hz) and Fast 120 rpm (2 Hz)
- Chosen based on measurements done previously to benchmark

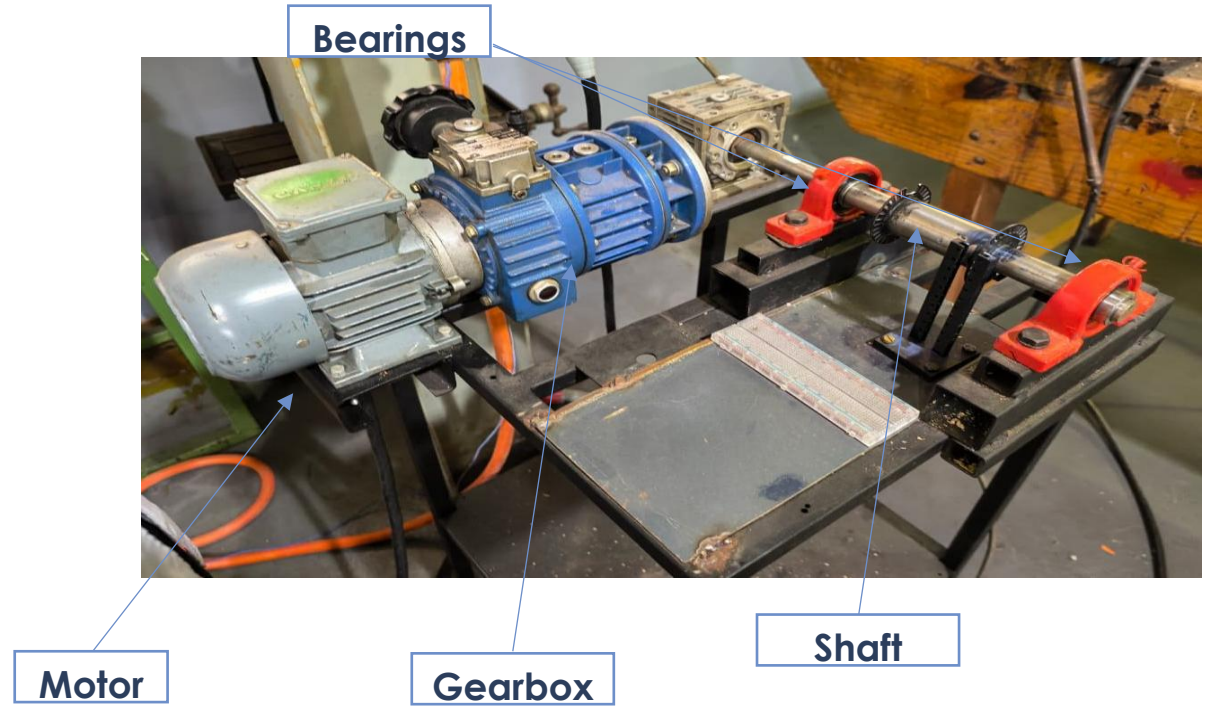


Figure 6: Test-rig for simulated drivetrain testing using FBGs

Methodology

Setup and Acquisition

Experimental matrix

66 rpm	Slow
120 rpm	Fast
Y + Z	Sensor orientations
500 Hz	Sampling rate
SI255	Hyperion interrogator

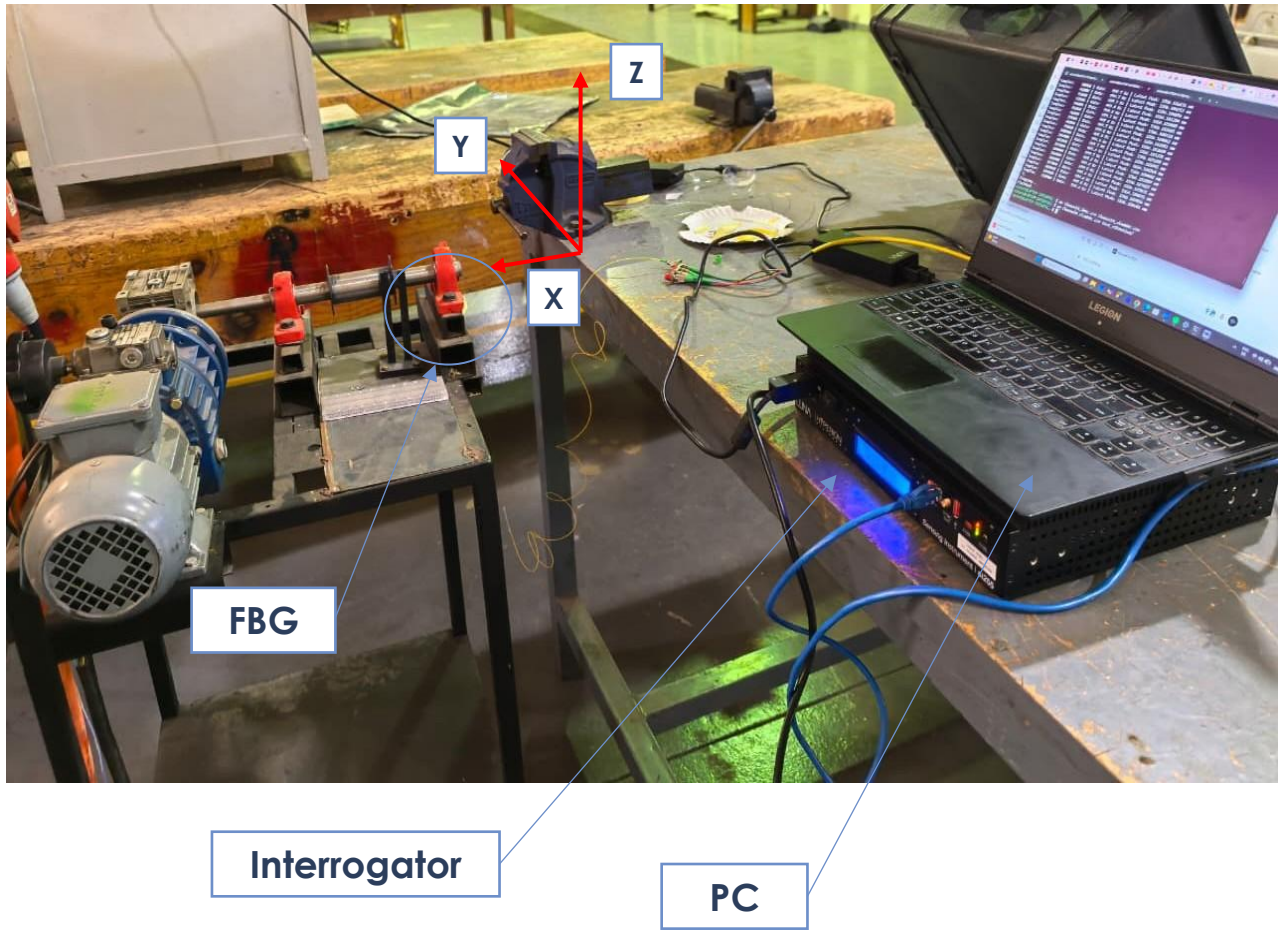


Figure 7: Setup of data acquisition instruments

Methodology

Data Analysis

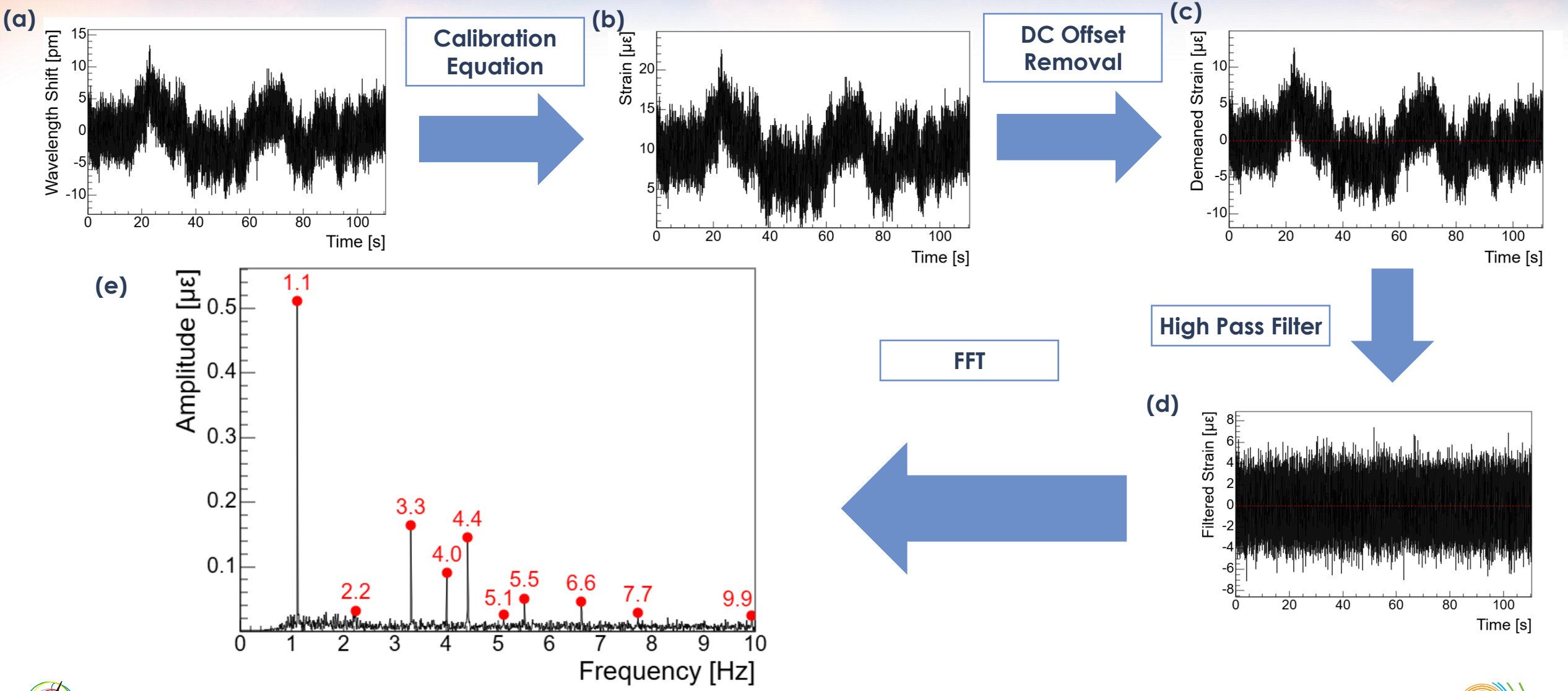
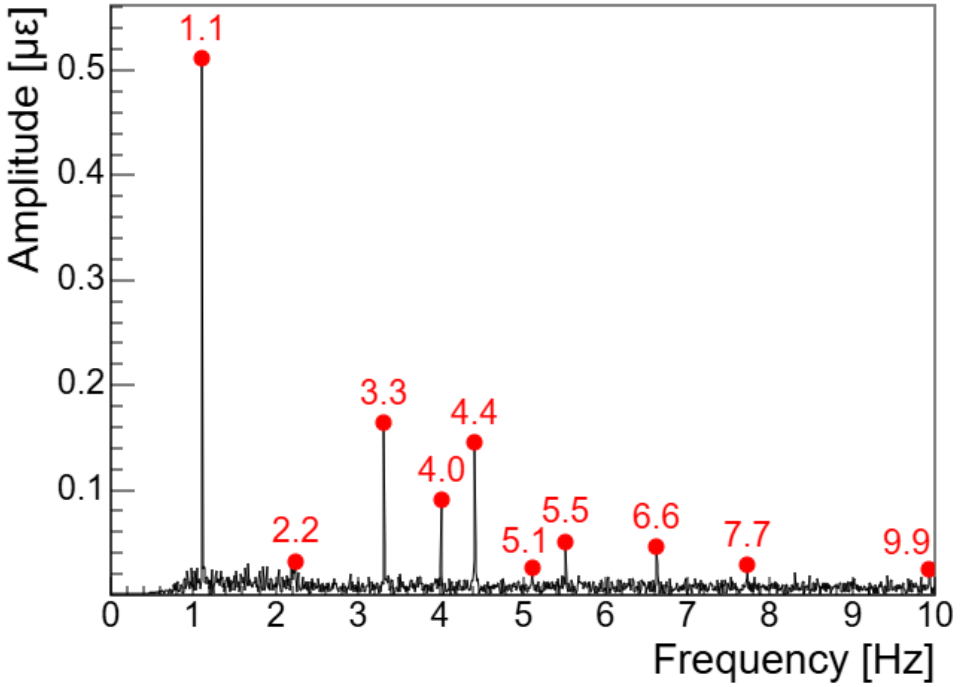


Figure 8: Data filtering and analysis process showing (a) wavelength shift; (b) converted wavelength shift to strain; (c) demeaned strain variation; (d) high-pass filtered strain and (e) FFT vibration spectrum

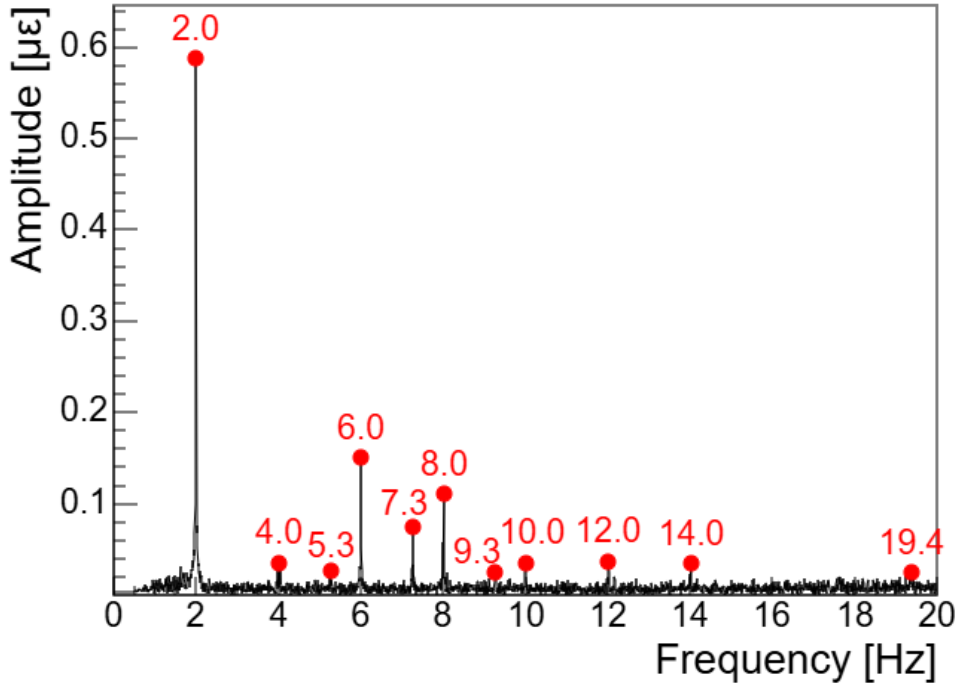
Results: Z-direction

Key result 1 — the FBG recovered shaft speed

- Z-direction spectra show the rotational frequency directly
- Harmonics of running speed shown
- Anomalous signals seen between 3rd and 4th harmonic and 4th and 5th.



66 rpm → 1.1 Hz



120 rpm → 2.0 Hz

Results: Z-direction

Key result 2 — possible bearing effects?

- Calculated bearing characteristic frequencies to probe anomalous signals
- Most interesting is the BPFO

Frequency	Order	66 rpm	120 rpm
Fundamental Train Frequency (FTF)	0.393 X	0.43 Hz	0.79 Hz
Ball-Pass Frequency of Outer Race (BPFO)	2.231 X	2.45 Hz	4.46 Hz
Ball-Pass Frequency of Inner Race (BPFI)	3.537 X	3.89 Hz	7.07 Hz
Ball Spin Frequency	5.463 X	6.01 Hz	10.93 Hz

Results: Z-direction

Key result 2 — possible bearing effects?

- Calculated bearing characteristic frequencies to probe anomalous signals

66 rpm

Measured	Calculated BPFO
4.0 Hz	3.89 Hz

Difference

~1.5%

120 rpm

Measured	Calculated BPFO
7.3 Hz	7.07 Hz

Difference

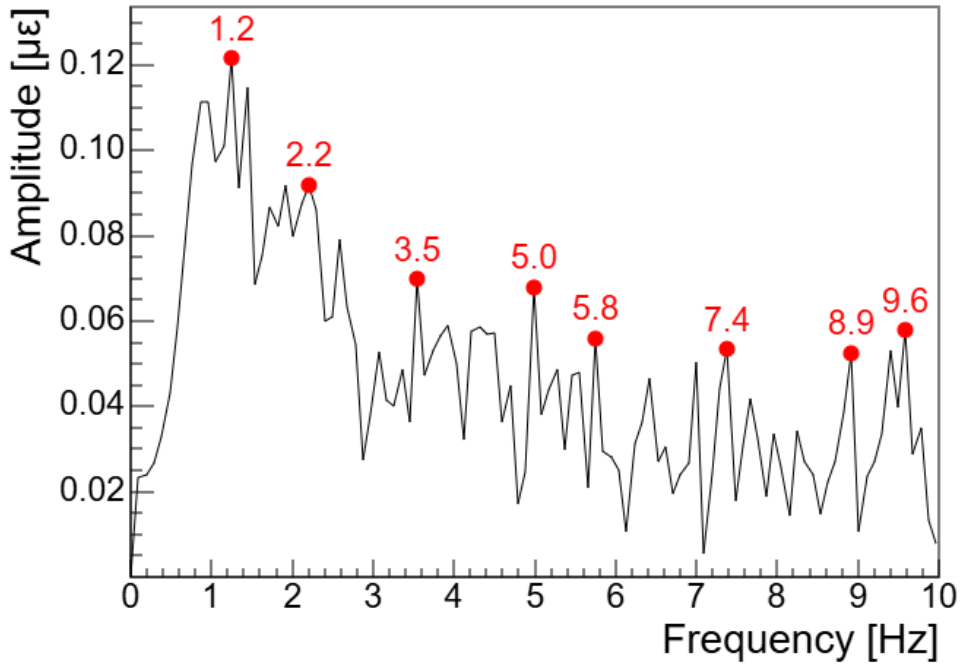
~3.3%

Interpretation: encouraging correspondence, but FFT peaks alone do not prove an outer-race fault; harmonics, resonances and sidebands remain possible.

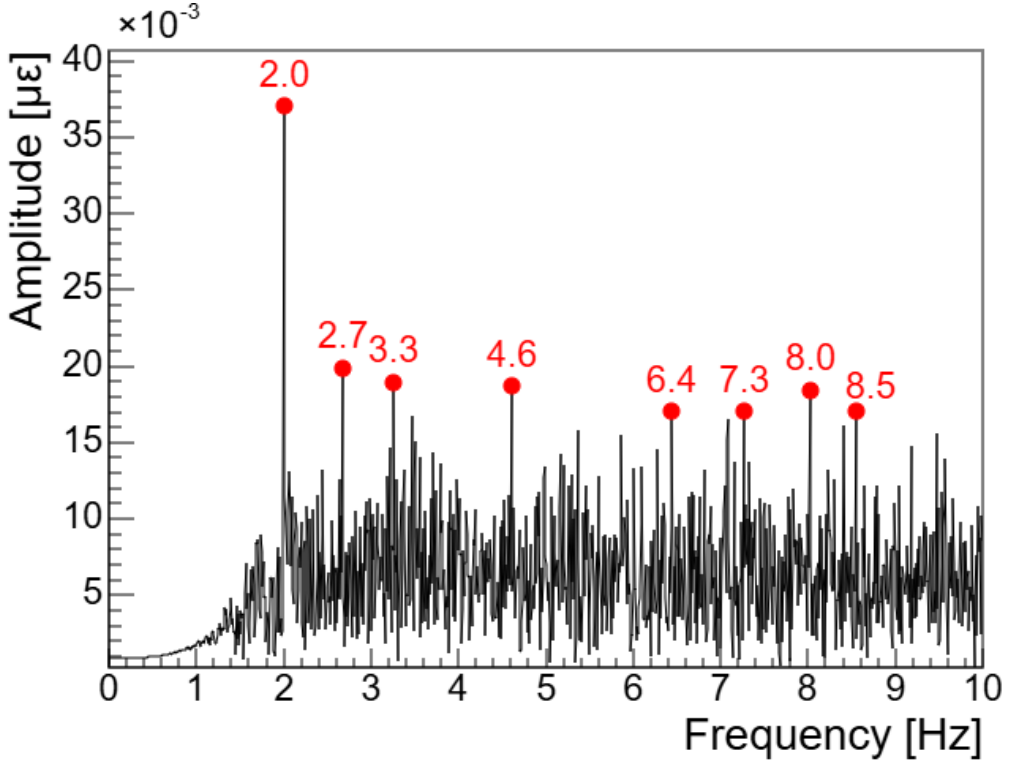
Results: Y-direction

Key result 3 — sensor orientation strongly affects amplitude

- Slow speed not picked at exactly 1.1 Hz – could be true reading
- Fast picks up shaft speed
- Intensity not same as Z and no other frequencies of interest seen (noise heavy)



66 rpm → 1.1 Hz

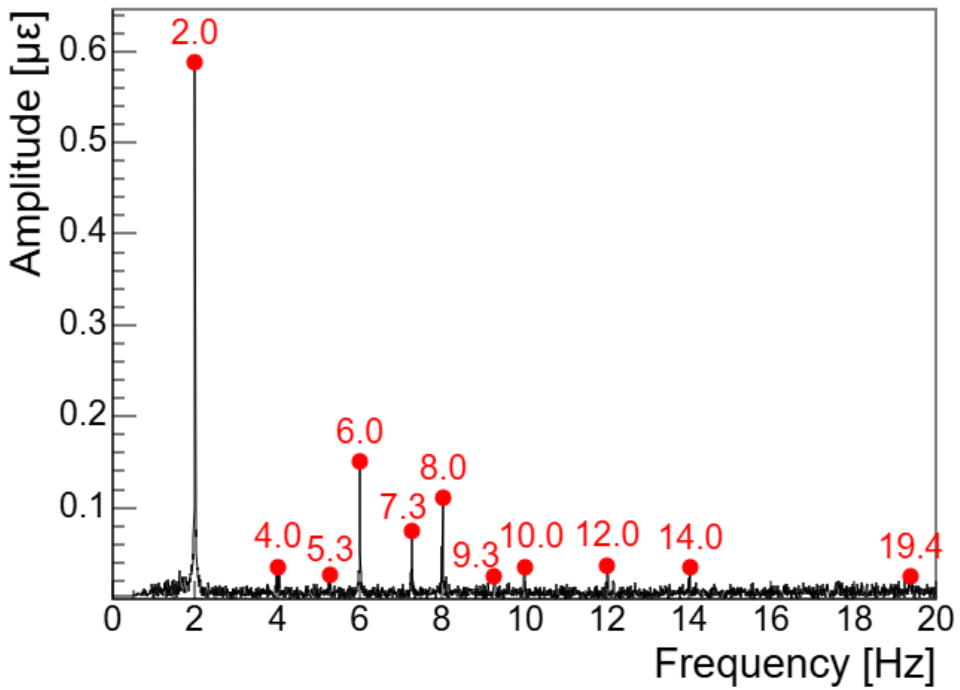


120 rpm → 2.0 Hz

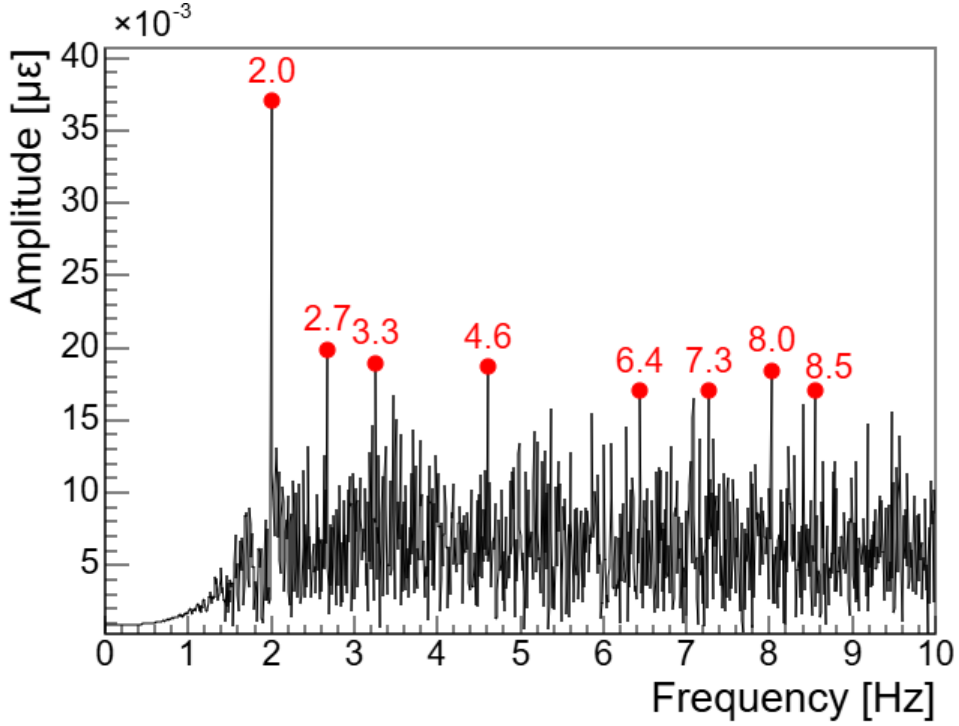
Results: Y-direction

Key result 3 — sensor orientation strongly affects amplitude

- Fast-speed spectra: same 2.0 Hz shaft frequency, very different response magnitude



Z direction



Y direction

Results

What did the FBG tell us?

01	**Rotational behaviour**	Shaft-running frequency detected at both speeds.
02	**Harmonic content**	Higher-order mechanically induced components were resolved.
03	**Bearing-frequency candidates**	4.0 and 7.3 Hz closely tracked calculated BPFO values.
04	**Directionality**	Response magnitude depended strongly on sensor orientation.
05	**System condition**	Strong running-speed peaks were consistent with shaft imbalance.

Why this matters for African wind energy

Potential implications if the approach is validated at turbine scale

POWER

Earlier identification of abnormal drivetrain behaviour could support availability and reduce unplanned downtime.

PEOPLE

Compact optical sensing could complement maintenance teams with continuous or targeted drivetrain diagnostics.

INDUSTRY

Locally developed FBG capability can strengthen condition-monitoring research, skills and technology development.

This study demonstrates feasibility — not yet a field-validated predictive-maintenance system.

Conclusion

From feasibility study to validated condition monitoring

Current study	Validation	Long-term goal
Lab drivetrain 2 speeds • 2 axes FBG + FFT	Repeated tests More speeds Accelerometer comparison Controlled bearing faults	Multiplexed FBG network for drivetrain condition monitoring and predictive maintenance

A strand of optical fibre can “listen” to a drivetrain.

Discussion: Could fibre-optic sensing complement conventional turbine condition-monitoring systems?
Collaboration partners for on-site testing?

THANK YOU

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References

[1] M. Wilkinson, F. Spianto, and M. Knowles, "Towards the Zero Maintenance Wind Turbine," in Proceedings of the 41st International Universities Power Engineering Conference, Sep. 2006, pp. 74–78, doi: 10.1109/UPEC.2006.367718.

[2] N. Y. Yürüşen, J. Tautz-Weinert, S. J. Watson, and J. J. Melero, "The financial benefits of various catastrophic failure prevention strategies in a wind farm: Two market studies (UK-Spain)," in Journal of Physics: Conference Series, 2017, vol. 926, no. 1, p. 12014.

[3] R. Grigore and M. Ion, Some Considerations About Operation and Maintenance of Wind Turbine. 2014.

[4] J.-Y. Hsu, Y.-F. Wang, K.-C. Lin, M.-Y. Chen, and J. H.-Y. Hsu, "Wind turbine fault diagnosis and predictive maintenance through statistical process control and machine learning," Ieee Access, vol. 8, pp. 23427–23439, 2020.

[5] T. Xu, X. Zhang, and W. Sun, "Intelligent fault warning method for wind turbine gear transmission system driven by digital twin and multi-source data fusion," Applied Sciences, vol. 15, no. 15, Art. no. 8655, Aug. 2025, doi: 10.3390/app15158655.

[6] Z. Ma, Y. Liu, D. Wang, W. Teng, and A. Kusiak, "Cyclostationary analysis of a faulty bearing in the wind turbine," J. Sol. Energy Eng., vol. 139, no. 3, Art. no. 031006, Jun. 2017, doi: 10.1115/1.4035846.

[7] International Renewable Energy Agency (IRENA), Renewable Energy Technologies: Cost Analysis Series—Wind Power, vol. 1, Power Sector, issue 5/5. Abu Dhabi, United Arab Emirates: IRENA, Jun. 2012.

[8] Y. Dalgic, I. Lazakis, I. Dinwoodie, D. McMillan, and M. Revie, "Advanced logistics planning for offshore wind farm operation and maintenance activities," Ocean Eng., vol. 101, pp. 211–226, Jun. 2015, doi: 10.1016/j.oceaneng.2015.04.040.

[9] S. Faulstich, B. Hahn, and P. J. Tavner, "Wind turbine downtime and its importance for offshore deployment," Wind Energy, vol. 14, no. 3, pp. 327–337, Apr. 2011, doi: 10.1002/we.421.

[10] Falcetelli, A. Martini, R. Di Sante, and M. Troncossi, "Strain Modal Testing with Fiber Bragg Gratings for Automotive Applications," Sensors, vol. 22, no. 3. 2022, doi: 10.3390/s22030946.