Distributed Optical Fibre Strain Sensing for Subsea Power Cable Monitoring: Dynamic Displacement Measurement via Brillouin Gain Spectrum Analysis

Dr. Madhubhashitha Herath[1] and Prof. James Gilbert[2]
[1] School of Engineering and Technology, Faculty of Science and Engineering, University of Hull, Hull, United Kingdom
[2] Energy and Environment Institute, University of Hull, Hull, United Kingdom

Introduction

Floating Offshore Wind is expanding rapidly, driving demand for reliable dynamic power cables. Failures are expensive and disruptive, highlighting the need for robust condition-monitoring solutions [1]. Among available techniques, Brillouin Optical Time Domain Reflectometry (BOTDR) is widely used for distributed static and quasi-static strain measurements, as it determines strain by tracking variations in the Brillouin frequency shift (BFS) [2]. BOTDR measures absolute strain over tens of kilometres in standard fibre and separates strain from temperature without auxiliary fibres. This study examines how dynamic strain influences Brillouin Gain Spectrum (BGS) characteristics and evaluates the potential of BOTDR-based sensing for dynamic strain identification, with future application to subsea power cable monitoring.

Methods

A standard telecom-grade fibre was subjected to dynamic loading under two experimental configurations. In the first, a 5-m bare fibre underwent cyclic tensile loading; in the second, a bare fibre bonded to the surface of a slender cylindrical structure (SCS) was exposed to cyclic flexural loading. The tensile and flexural cyclic loadings were applied using an electrically driven linear actuator controlled by a microcontroller unit.

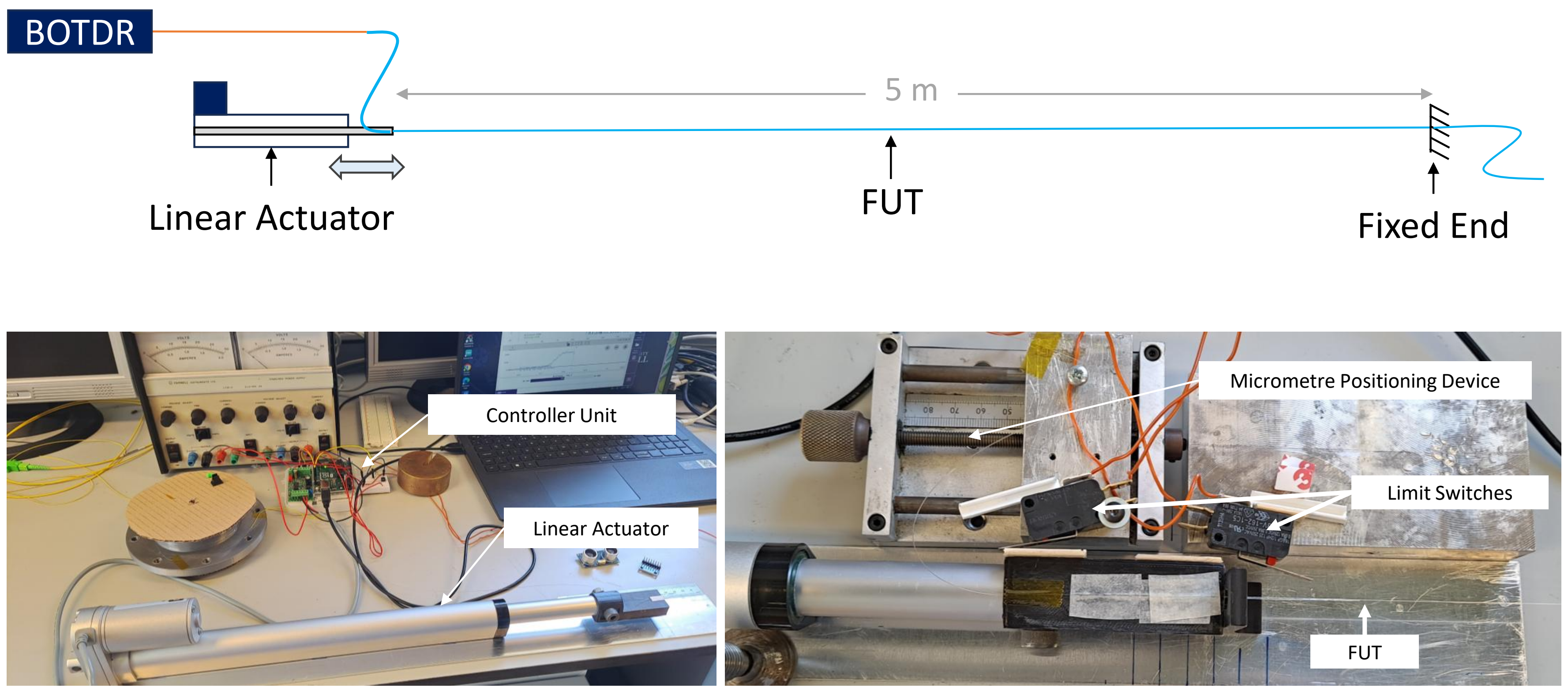

Figure 1: Experimental Setup of the Cylic Tensile Test

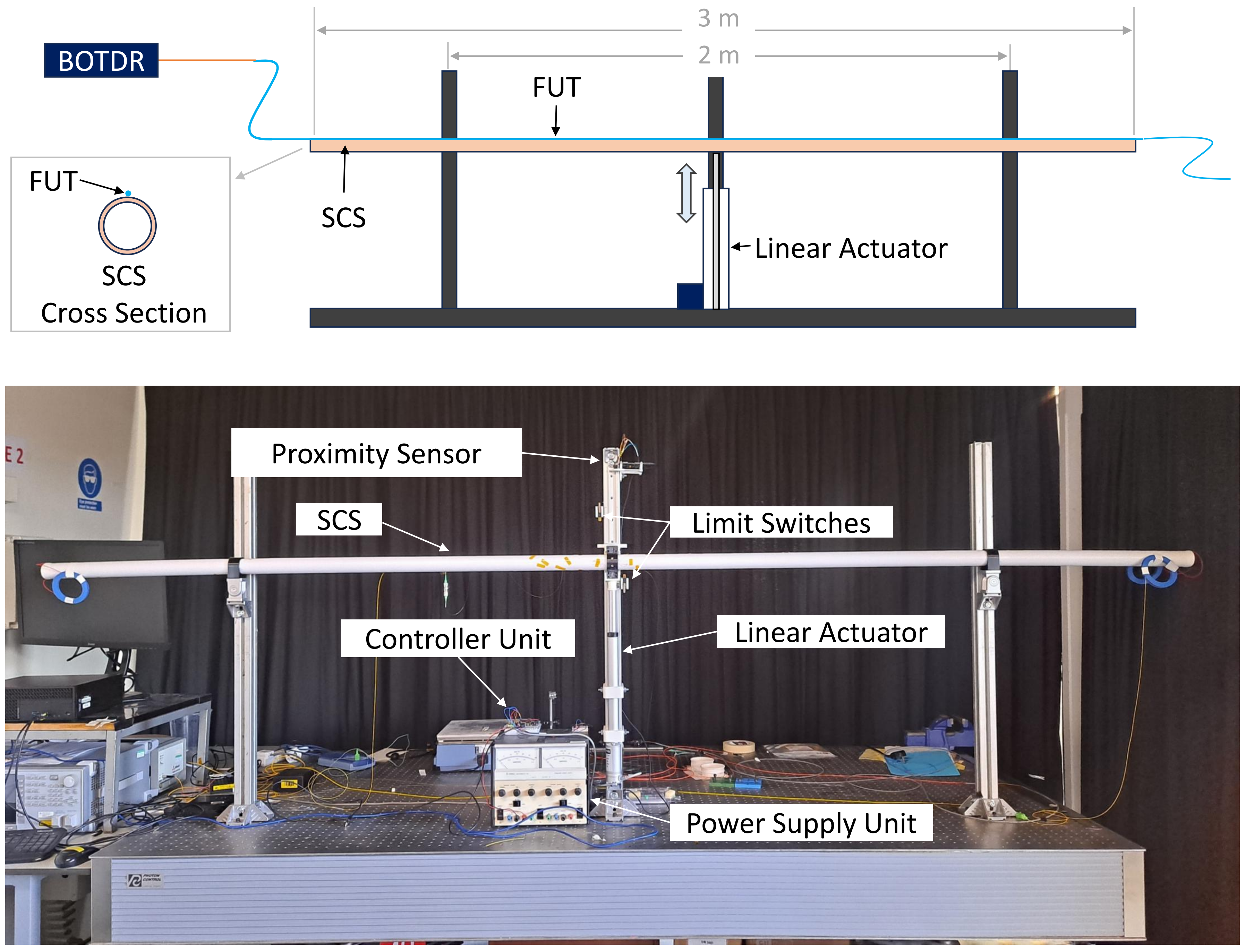

Figure 2: Experimental Setup of the Cylic Flexural Test

The BGS was recorded using a “VIAVI FTH-9000” Brillouin optical time-domain reflectometer (BOTDR). In both cases, the BGS at the midpoint of the fibre under test (FUT) was considered for the analysis. For tensile loading, the analysis point was 2.5 m from the fixed end, while for flexural loading it was located at the SCS midspan, where axial strain peaks. Tensile and flexural tests were conducted at five levels of low-frequency dynamic displacement, designated DTT1-DTT5 and DFT1-DFT5, respectively.

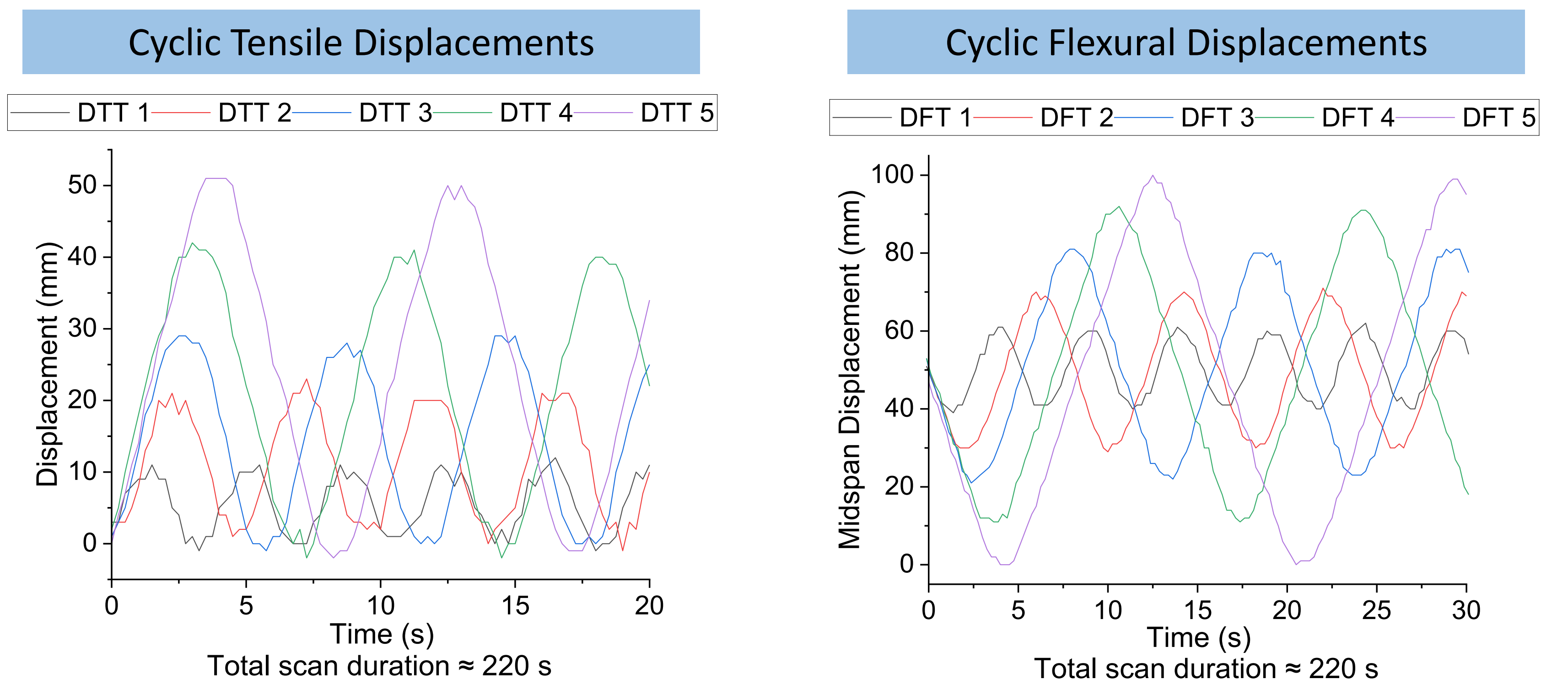

Figure 3: Applied displacement cycles in tensile and flexural loading

Results

As the dynamic displacement increased, the BGS exhibited progressive broadening. To quantify this behaviour, the dispersion of the BGS was evaluated using the standard deviation. The baseline standard deviation at zero displacement was treated as a constant variance term and removed using a root-sum-of-squares subtraction. The resulting spectrum spread showed an approximately linear dependence on displacement range.

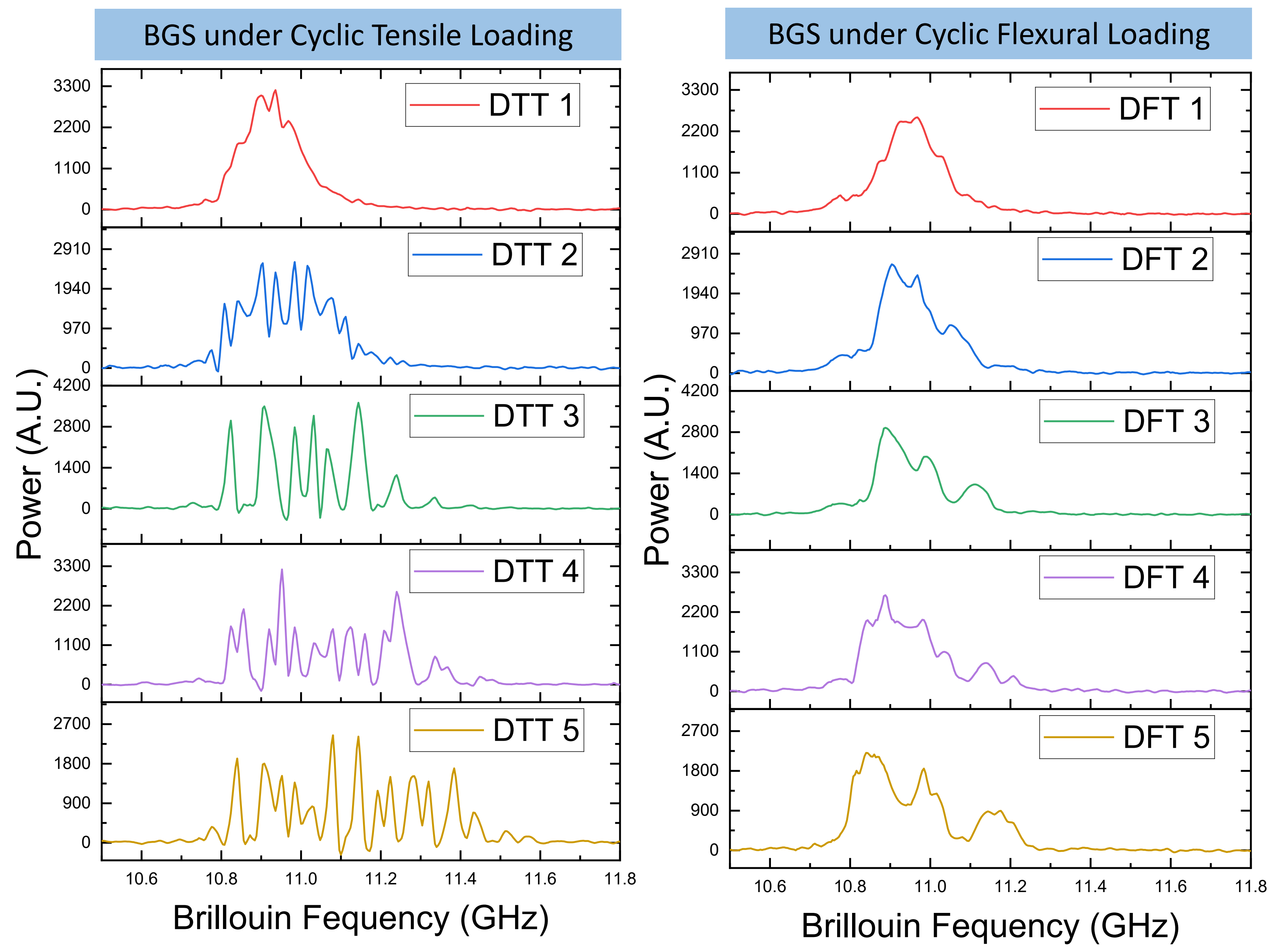

Figure 4: Brillouin Gain Spectrum at the midpoint of the fibre under test

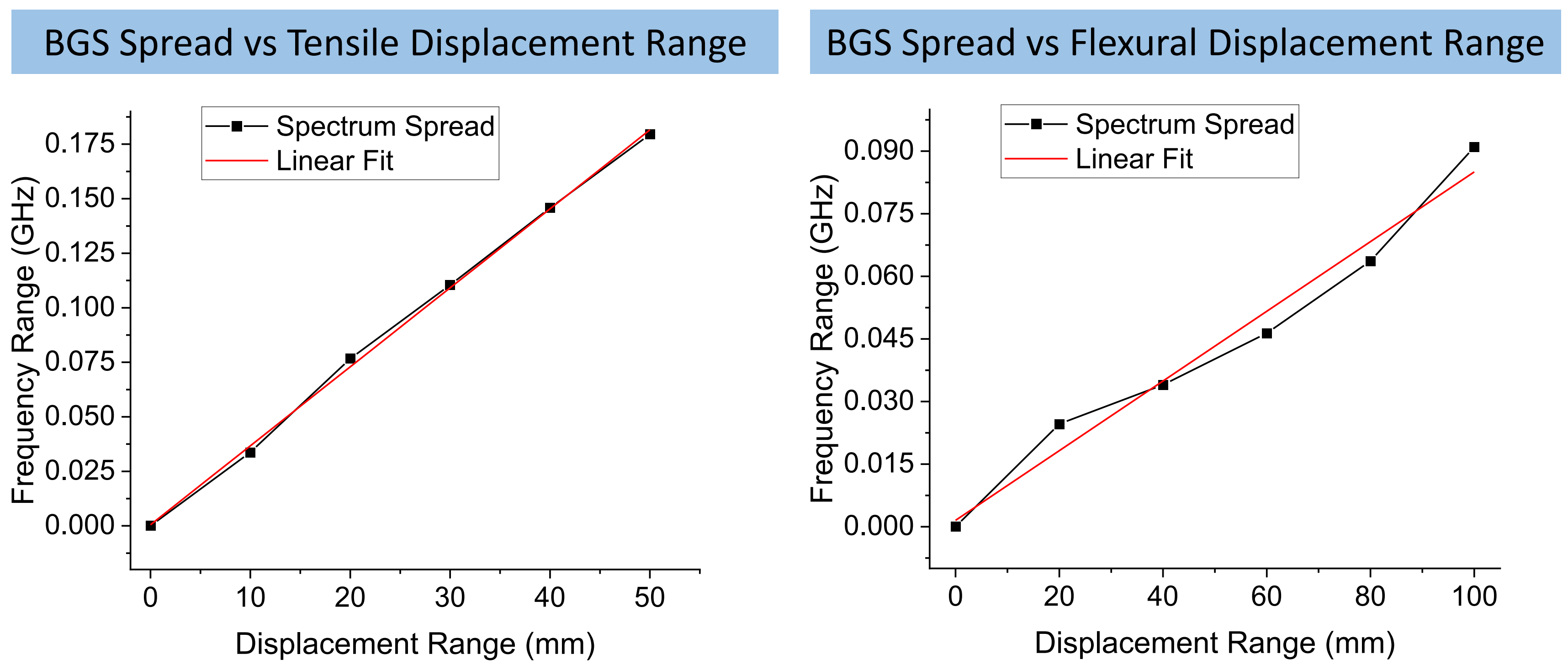

Figure 5: Relationship between BGS Spread and Dynamic Displacement Range

Conclusion

Dynamic loading has broadened and distorted the BGS, affecting conventional BFS-based strain measurements. Evaluating BGS features such as spectrum spread offers a practical means of estimating dynamic displacement. This demonstrate the potential of BGS-derived parameters for characterising both static and dynamic behaviour in subsea power cables.

References

1. Cerik, B.C. and L. Huang, Recent advances in mechanical analysis and design of dynamic power cables for floating offshore wind turbines. Ocean Engineering, 2024. 311: p. 118810.
2. Herath et al., Evaluation of bending deformations in slender cylindrical structures using distributed optical fibre strain sensing. Sensors, 2025. 25: p. 7366.

Engineering and Physical Sciences Research Council

Supergen Offshore Renewable Energy