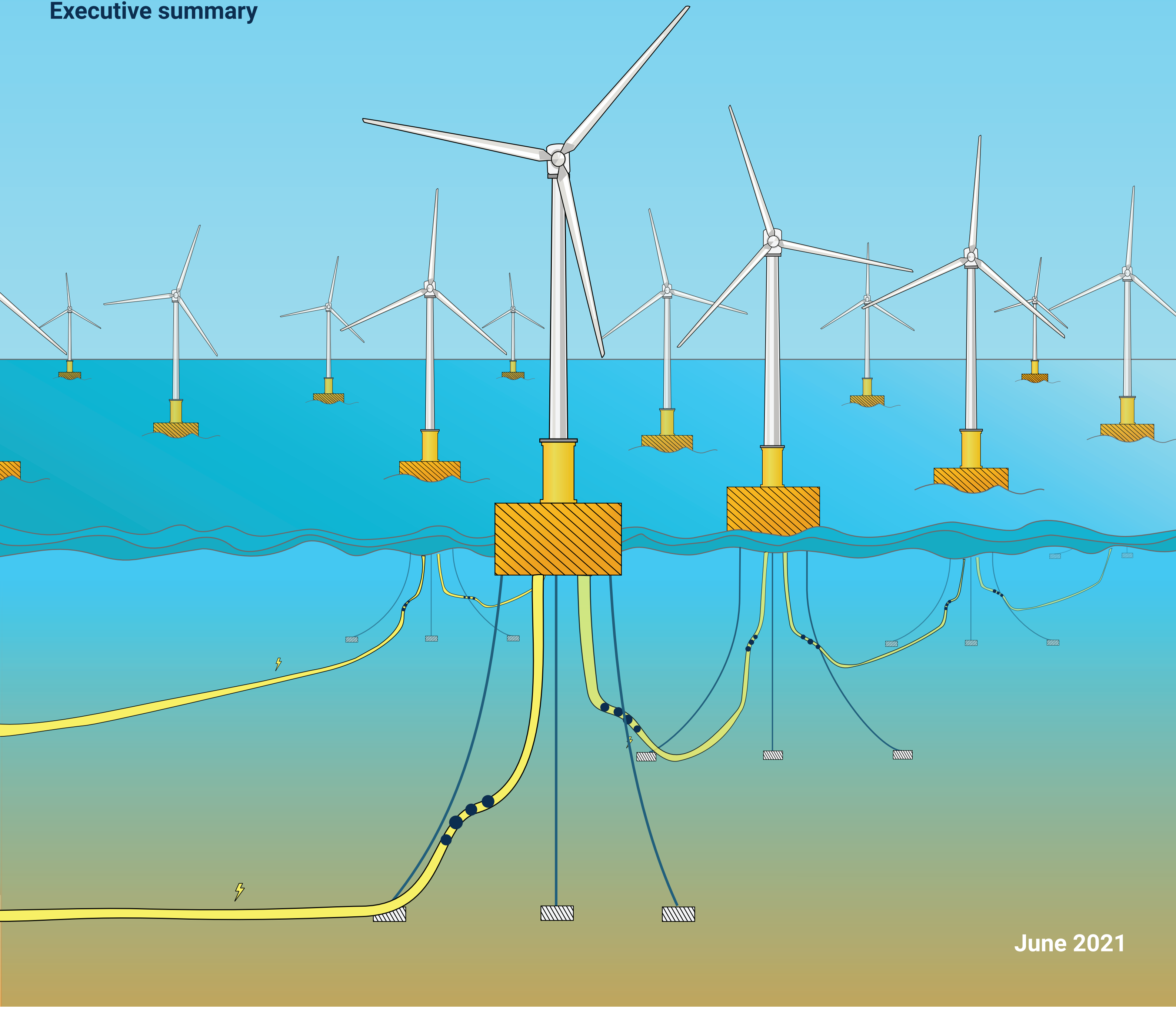
Autonomous Mooring Line Fatigue Monitoring

Floating Wind Technology Acceleration Competition

Executive summary



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FLW JIP, formed in 2016, is a collaborative research and development initiative between the Carbon Trust, and fifteen leading international offshore wind developers: EDF Renouvelables, EnBW, Equinor, Kyuden Mirai Energy, Ocean Winds, Ørsted, Parkwind, RWE, ScottishPower Renewables, Shell, SSE Renewables, TEPCO, TotalEnergies, Vattenfall, and Wpd.

Authors

Conor Casey
Lead Mechanical Engineer
Conor.casey@technologyfromideas.com

Ross Wilson
Senior Mechanical Design Engineer
ross.wilson@csignum.com

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Technology from Ideas Ltd. is a company registered in Ireland under Company Number: 408488 with its Registered Office at: 6 Charlemont Terrace, Crofton Road, Dun Laoghaire, Co. Dublin

CSignum Ltd. is a company registered in Scotland under Company Number: SC 666714 with its Registered Office at: Unit 9B, Pyramids Business Park, Bathgate, EH48 2EH

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EXECUTIVE SUMMARY

1.1 Introduction

Technology from Ideas (TfI) and CSignum (previously WFS Technologies Ltd) were successful applicants to the Floating Wind Technology Acceleration Competition run by the Carbon Trust's Floating Wind Joint Industry Project and funded by the Scottish Government. The collaboration proposed to develop a solution for autonomous full life fatigue monitoring of mooring lines by utilising a TfI SeaSpring to generate power for integrated load monitoring and CSignum's HydroFi subsea wireless communications technology for transmission of data.

1.2 Background

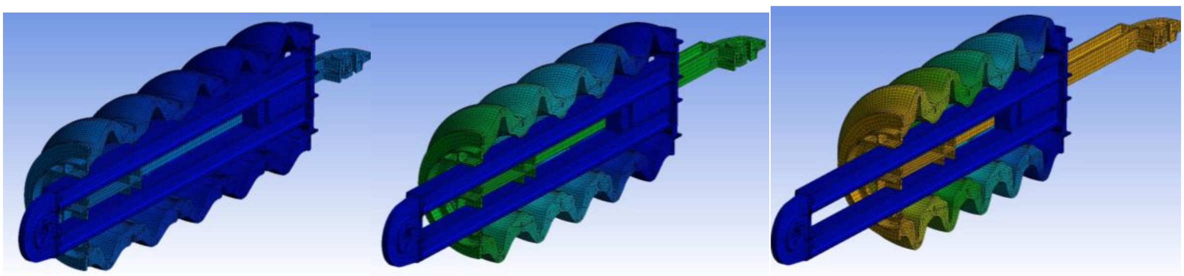
As the build out of Floating Offshore Wind Turbines (FOWT's) accelerates, there is an increasing focus on the requirements for mooring integrity management, driven by the certification bodies and several high-profile mooring line failures. As in the upstream oil and gas industry, there is a requirement for all floating wind farm developers to ensure compliance with codes and standards for the inspection and maintenance of their mooring systems, thereby ensuring that robust integrity management systems are in place (e.g., API RP 2SK, DNVGL-OS-E301, DNVGL Nobel Denton:0032/ND Guidelines for Moorings)

Failure mode, effects, and criticality analyses (FMECA), are carried out by developers to ensure full risk assessments can be performed to mitigate potential integrity issues. The ability to provide full life autonomous load monitoring of mooring lines will provide a layer of rigour to the mooring chain integrity management system.

Load monitoring is typically constrained by the power required for the monitoring and transmission of data. It often requires battery packs which need to be periodically replaced (adding to the maintenance tasks), or else requires cables from the platform to the sensor (e.g. load pins) which are a major failure point. Cables are also used for communications and experience has shown that mooring load monitoring systems with cables regularly fail after just a few weeks or months. Constant replacement of such components across a wind farm, with hundreds of mooring lines, is very expensive.

TfI's solution is to integrate TfI's SeaSpring with load sensing, power generation, and wireless subsea communications to enable autonomous full life fatigue monitoring. Operating over the entire life of the mooring line, the solution aims to mitigate the risks associated with existing load measuring solutions, the power requirements, and the reliability of cabled connections.

The TfI Sea Spring consists of a large, convoluted polymer bellow which is compressed between two metal plates as the tension in a mooring line increases. It is this compression which will be used to generate the power, and the internal metal structure will be used to measure the loads.



The piezoelectric ceramics are embedded within the end plate, fully sealed, and protected from the marine environment. The number of piezoelectric ceramics used is determined based on power requirements and the model of SeaSpring. This arrangement is scalable for all SeaSpring sizes.

CSignum's HydroFi low frequency radio technology delivers wireless communications through water. CSignum's technology only requires low-energy transmission between nodes and will communicate through the water-air boundary, removing the requirement for cables. While offering lower transmission rates than optical technologies and shorter ranges than acoustic solutions, it is not affected by water quality or multipath effects caused by shallow water applications and delivers an excellent balance between range and data rate. Power requirements are also lower offering a longer life from available power. There is the option of data analysis algorithms on board the device, further reducing the amount of data which requires transmission and reducing the overall required power capacity.

1.3 Research Questions

The objective of this project was to develop autonomous full life fatigue monitoring through the integration of power generation, load sensing, and communication with TfI's polymer spring.

To achieve the above objective, the following research questions were developed:

Research Questions	
1	Is it feasible to develop full life fatigue monitoring for a FOWT deployment by integrating power generation, load sensing, and wireless communication into a polymer spring?
2	What options exist for integrated power generation, load sensing, and wireless communications and which choice is most suitable for integration into a polymer spring?
3	What data is required to develop a fatigue profile of a mooring line?
4	Can enough power be generated to power the sensing and communications?
5	How can this concept be integrated into a TfI SeaSpring?

To answer these questions, the project was broken into two phases:

- Feasibility Study: To establish the technology on one of TfI's FOWT scale mooring springs.
- Integration: To integrate the technology into an existing 1/5th scale Tfi SeaSpring and test it.

Feasibility

During the feasibility phase we validated the use of piezoelectric ceramics as a suitable power generation source. Several options were compared; including linear generators and hydroelectric turbines, concluding that piezoelectric plates were the most promising. Piezoelectric ceramics are small, generate the required power, and have no moving parts, making them the preferred choice for powering a sensor platform in a TfI SeaSpring.

CSignum's HydroFi radio platform was selected as the preferred option once the range requirements and physical location of the nodes were considered. Other options considered were Acoustic and Optical.

Many load measuring options were considered, with a strain gauge-based tension measurement system preferred. This enables fatigue damage calculations and is of clear benefit to the operator. It removes the requirement for the existing load shackle solution which is prone to damage.

Finally, in the feasibility phase of the project, a fatigue model was developed that could be implemented on a FOWT mooring spring. This model converts strain readings from the sensor spring system to fatigue damage readings on board the SeaSpring. These damage calculations are then sent back to the developer.

Integration (1/5th Scale Mooring Spring)

The integration phase implemented the results of the feasibility study into a 1/5th scale Tfi SeaSpring. Load sensing, power generation, and radio communications were designed and integrated into TfI's 1/5 Scale SeaSpring and tested in the University of Exeter on the DMaC test rig. The strain gauges were installed directly onto the metalwork themselves, ensuring a good bond. To protect them from moisture and damage, they were covered with a two-part polymer coating.

To facilitate the rig testing, the strain gauges and piezo electronics were installed directly on the spring, with the other components installed beside the test rig and wired into the spring. This allowed more access to the electronics, simplifying the testing process.

Testing of the strain gauges, polymer spring, and communications took place in the University of Exeter on the DMaC test rig. Testing of the power generation took place in University College Cork at the LIR NOTF (National Ocean Test Facility).

The strain gauges were calibrated and operated during polymer testing. The gauges operated well throughout testing, providing plenty of data to analyse. Further testing is planned to refine the calibration scale factor.

The piezoelectric ceramics were characterised against force and period to validate the manufacturers specification. It was noted that piezo voltage output is specified on high frequency applications (kHz) while this application is in the low Hz range. While the same power is generated, this resulted in lower voltages and higher currents than specified. Following characterisation, the piezoelectric ceramics were operated in a power generating mode. Due to the small scale of the SeaSpring and frequency of operation, the voltage did not reach the minimum threshold for charging a suitable battery for operating the strain gauges. At the 1/5th scale, a further DC-DC converter could be included to boost voltages and achieve the minimum threshold for the battery and strain gauges. However, the power at the 1/5th scale (~8mW) is lower than the FOWT scale SeaSpring (32-45mW) and to implement this system at 1/5th scale, it may be necessary to add a second pressure plate, reduce power requirements by reducing duty cycle, reduce the number of sensors, or remove wireless communications.

More power and higher voltages are expected on a FOWT scale system which can accommodate the autonomous load monitoring system (power, sensing, wireless communications) as described throughout this project. If additional power is available, additional sensors can be included as required by the floating wind developer.

1.4 Key Findings

- Feasibility
    - There is enough power in one pressure plate to operate full-life fatigue monitoring on a FOWT scale SeaSpring, including: continuous load monitoring, on board data manipulation, and daily burst transmissions of fatigue data.
    - A single pressure plate, sized for a representative FOWT deployment, can produce an estimated average power of 32mW to 45mW from the most common sea state. This is

enough to operate sensors and communications with power available for an alarm overhead.
    - Radio is considered the most robust wireless technology for this application as it can transmit across the water air boundary and through shallow water.
- Load Monitoring
    - Load monitoring was demonstrated with the installation of strain gauges onto the metalwork of a 1/5th scale polymer spring.
- Communication
    - Communication of strain gauge data was successfully demonstrated across the laboratory environment.
- Power Generation
    - Piezoelectric ceramics typically operate in high frequency applications where mooring line loads are considered relatively low frequency. While the power produced remains the same, the induced voltage in low frequency applications is lower than specified by the piezo manufacturer.
    - Understanding this effect has enabled better design of the power management electronics.
- System Integration
    - The optimal configuration of the system logs the strain gauge data and converts it into mooring fatigue damage on board the spring. This fatigue damage data is transmitted in bursts back to the platform.

1.5 Conclusion

TfI & CSignum developed a technology for generating power on TfI's SeaSpring and wirelessly transmitting mooring line loads and fatigue data to the relevant parties responsible for mooring line management. This data will play an integral role in mooring integrity management systems as part of risk-based monitoring.

The project was a part of the Floating Wind Technology Acceleration Competition run by the Carbon Trust's Floating Wind Joint Industry Project and funded by the Scottish Government.

This technology was shown to be technically and commercially feasible and demonstrated at 1/5th scale in the University of Exeter's DMaC test facility and in Ireland's National Ocean Test Facility, LiR.