Deflection Monitoring and frequency response of a Ship using GPS and Fibre Optic based sensors

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ABSTRACT

Kinematic GPS and GNSS has been used as a tool to monitor the deflections and natural frequencies of large structures, and hence Structural Health Monitoring. In addition, fibre optic based measuring systems have been used to measure the long-term deformations of natural and engineered structures. In this paper, we discuss the use of both GPS and fibre optic based measuring systems to measure the deflections and natural frequencies of specific locations on a ship.

Field tests were conducted on the 138 m long Smyril ship on the Faroe Islands. The one-way journey time between Tórshavn and Suðuroy is 2 hours, with a distance of approximately 68 km.

Surveys were carried out on the 1 August 2017 and on the 12, 13 and 14 February 2018. Fibre optic sensors of three different configurations were placed within the ship, one at the bow and two in the engine room, gathering data at 1 kHz. Two GPS antennas were placed on either ends of the roof of the ship's bridge, and a third at the stern of the ship, all gathering data at 1 Hz.

This paper presents details of the configuration of the surveys and shows results from both the GPS and fibre optic units. A fundamental frequency of around 0.11 Hz was extracted from the GPS data, illustrating this as being the frequency of the motion of the ship at sea. Higher frequencies due to the vibration of the ship mainly due to the engine were too small for the GPS to pick up. The fibre optic sensors, however, were much more sensitive and could pick up a variety of frequencies, and changes in frequencies due to the ship movement and engine operation.

I. INTRODUCTION

Previous research has used GPS (Global Positioning System) and GNSS (Global Navigation Satellite Systems) to measure the dynamic responses of tall buildings (Lovse et al., 1995) and long span bridges (Ashkenazi et al., 1996; Brown et al., 1999). Such research has seen the responses been measured using GNSS receivers capable of measuring multi frequency pseudorange and carrier phase data at rates of up to 10 Hz, 20 Hz and even 100 Hz (Msaewe et al., 2017). The use of GNSS receivers recording at such frequencies are suitable for generally open sky bridge environments whose main natural frequencies are of the order of 0.1 Hz to 1 Hz. Such movements are short term displacements. Nowadays, these measurements are used in commercial monitoring and analysis schemes placed on operational long span bridges, mainly in Asia (Roberts, 2014; Roberts et al., 2018). These can also supply data as an input into Structural Health Monitoring (SHM) systems.

Previous research has also seen the development and use of FBG (Fiber Bragg Grating) technology to measure the long-term deformations of infrastructure, such as roads, tunnels and embankments (Klug et al., 2014; Lienhart et al., 2013). Such measurements are made by using fibre optic cables and sensors that are either embedded into the structure, such as pouring the concrete around it, or attached on the surface of it through gluing it in place using epoxy resin. FBG sensors are capable of measuring data at rates of kHz but are traditionally used for measuring long term deformations over periods of up to many years.

This research investigates the integration of the short term displacement monitoring idea used in the bridge monitoring scenarios, with the high rate data capture and ability to work indoors of the FBG, in order to measure the magnitude in the time and frequency domains of the displacements of a ship due to the loading effects of the sea and the vibrations due to the engine during its journey. Field tests were conducted on a passenger ferry ship operating in the open sea in the Faroe Islands, gathering both carrier phase GPS data on the ship's deck and FBG data from inside the ship's hull.

The Smyril (Merlin) is a 138 m long passenger and vehicle ferry, Figure 1 (top), that operates between the capital city of the Faroe Islands, Tórshavn, and the ferry port of Krambatangi, on the southernmost island of Suðuroy, in the village of Tvøroyri, see Figure 1 (bottom). The Smyril disembarks 2-3 times daily from Krambatangi to Tórshavn. The one-way journey is a distance of 68 km and the journey time is 2 hours.

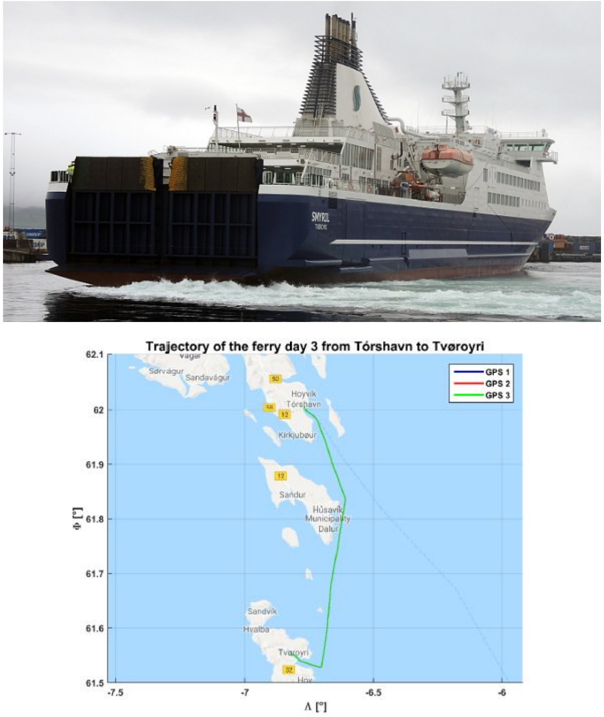


Figure 1. The Smyril (top); route of the Smyril (bottom)

II. FIELD TESTS

Field trials were conducted on two separate occasions. The first set of trials were carried out on the 1 August 2017, using the FBG sensors only. The FBG sensors were installed in two locations, these being in the engine room and at the bow of the ship, Figure 2.

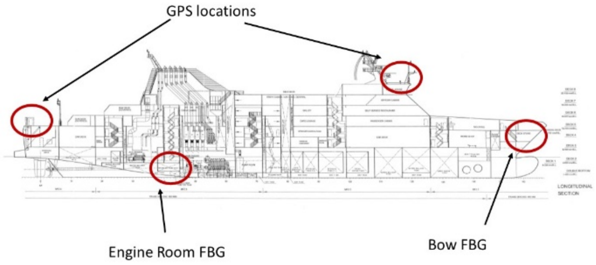


Figure 2. Location of the GPS antennas and FBG sensors

The FBG sensors in the bow location, Figure 3, were installed temporally with three magnetic mounts. Between theses mounts, a bare fibre FBG-chain, consists of two FBGs, were pre-strained.

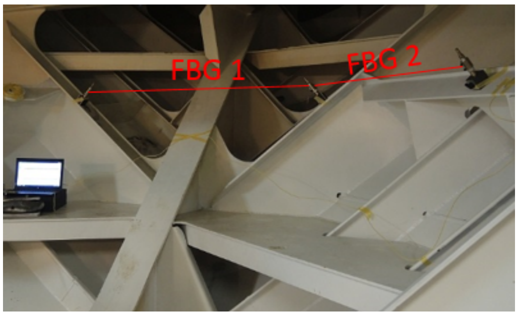


Figure 3. Location of the FBG sensors in the bow

The second location, Figure 4, consists of gluing the fibre optic cables and sensors onto the inside wall of the hull in the engine room using an epoxy resin.

Figure 4. Gluing of the FBG sensors in the engine room

The setup consists two different, commercially available, FBG sensor types, see Figure 5 (top) and Figure 6 (top). A strain rosette with three FBG sensing elements, were installed between two ribs, see Figure 5 (bottom). The strain rosette was mounted in a way, that one FBG sensor is horizontally aligned, see Figure 5 (middle).

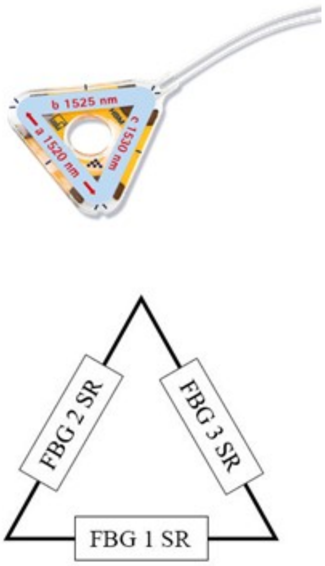
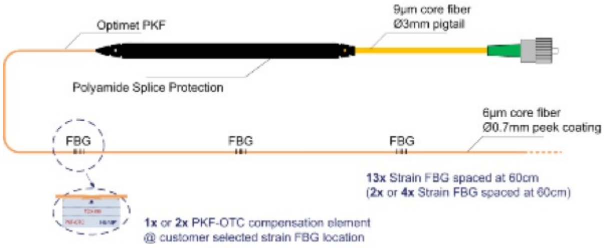


Figure 5. Commercially available strain rosette (HBM, 2019) (top); FBG sensor arrangement (middle); final mounting between two ribs (bottom)

The second sensor is a secondary buffered FBG-chain with 13 FBG elements, see Figure 6 (top). One sensor of this chain is a temperature sensor for compensation measurements. Furthermore, the mounting setup was carried out to measure vertical and horizontal movements. Therefore, two FBG sensors were arranged horizontally and ten vertically as shown in Figure 6 (middle). This sensor chain is mounted between two ribs next to the strain rosette.

With respect to the locations of the sensors, bow and engine room, only one section, bow or engine room was measured during any particular trip. In the engine room, all 15 FBGs were measured simultaneously with a sampling rate of 1 kHz.



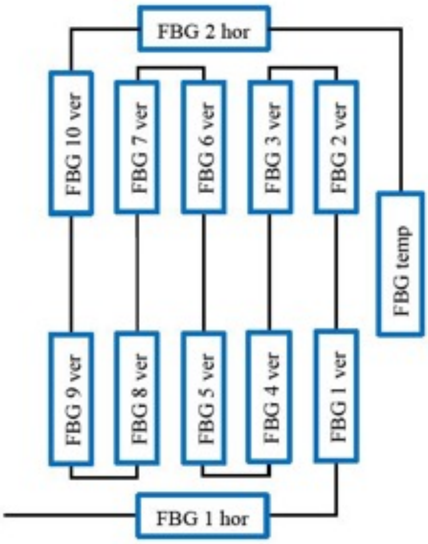


Figure 6. Commercial available strain chain (HBM, 2019) (top); FBG sensor arrangement (middle); final mounting setup (bottom)

During the field tests on the 1st August, the bow sensors gathered data during the 2-hour crossing from Tórshavn to Krambatangi, and the engine room setup gathered data on the return trip. During these tests, the weather and sea conditions were relatively calm.

The second set of trials were conducted on the 12th, 13th and 14th February 2018. The same locations as for the August surveys were used for the FBG sensors. In fact, the engine room sensors were left glued in situ from the previous experiments. This time, however, three Trimble 4700 dual frequency GPS receivers and micro antennas were located on the ship's deck. Two were placed on either side of the deck above the wheel house, and the third located at the back of the ship, Figures 2 and 7. The GPS receivers used are capable of gathering dual frequency GPS pseudorange and carrier phase data at a rate of 1 Hz. The GPS data were processed in a kinematic on the fly manner, using the Faroese Environment Agency's CORS station located in Tórshavn as the reference station, using RTKLIB (Takasu, 2013).

Figure 7. Location of the three GPS receivers

III. RESULTS AND DISCUSSION

The results presented in this paper are a small sub-set of the total. Figure 8 illustrates a block wise FFT (Fast Fourier Transform) of one of the FBG sensor's results in the engine room. This is for a 3-hour period, covering one of the ship's journeys. This included periods when the ship was static, as well as a 2-hour period of being in the open ocean during February. Events and the ship's maneuvers are labelled in Figure 8, clearly showing the effect of the waves and certain frequencies of the engine. Furthermore, the docking operation and related frequencies are clearly visible.

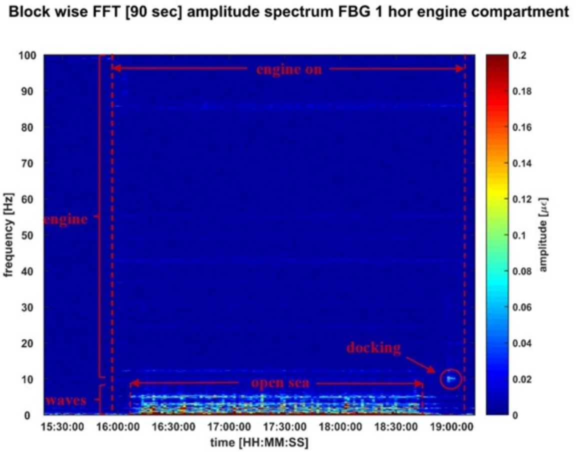


Figure 8. A block wise FFT of one of the FBGs in the engine room with some events labelled

Figure 9 illustrates the comparison between the GPS height variations at one of the GPS receivers located over the wheel house and the strain readings from FBG1 in the bow of the ship. A moving average filter is applied to the FBG data to filter it down to the same frequency as the GPS, at 1 Hz. It can be seen that the time domain deformations for the GPS (height changes) and FBG (strain variations) have a similar pattern, Figure 6 (top). It can also be seen that the frequencies identified from the two data sets are both the same, Figure 6 (middle and bottom). A main frequency of 0.11 Hz is observed for both the GPS and FBG data. This is the frequency of the rolling movement of the ship whilst in the open ocean, during a relatively rough crossing.

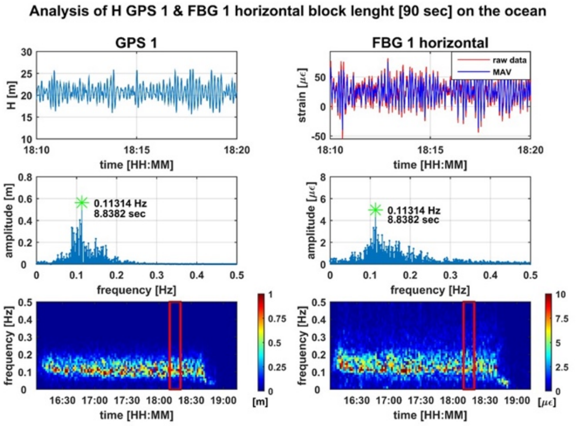


Figure 9: comparison of GPS height variations of GPS 1 and the strain readings of FBG 1 whilst the ship was travelling in the open ocean

We also compare different signal amplitudes at different environments for the FBG sensor chain. The maximum amplitude is plotted for a specific frequency range, see Figure 10.

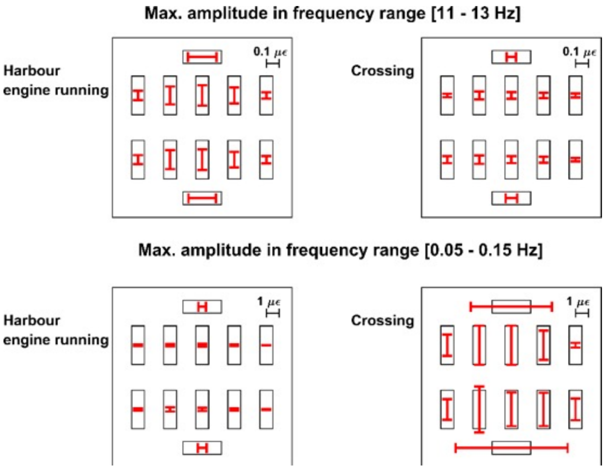


Figure 10. Comparison of the FBG chain amplitudes for different environment conditions

It is clearly apparent, that the sensors near the ribs have lower amplitudes. The biggest deformation of the hull of the ship is shown in longitudinal direction. This information can be important for optimization for further installations in a ship with less sensors.

A 3D visualization tool is developed at the University of Nottingham Ningbo China that allows for easy visual comparison of ship movement as measured by GPS and ship deformation as measured by FBG. The 3D model of the ship can be viewed from any direction throughout the animation to help understand particular movements. The tool is developed using the open source JavaScript libraries three.js and Chart.js. Figure 11 shows a screen shot of this software.

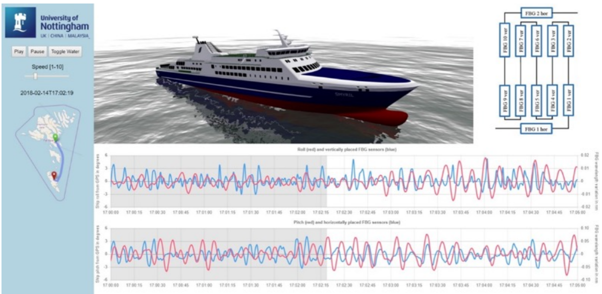


Figure 11: 3D visualization tool to compare the GPS and FBG deformations

IV. CONCLUSIONS

This paper introduces the application of GPS and FBG in order to measure the dynamic displacements of a ship, including the dynamic response of the ship's movement in open ocean as well as the vibrations through the ship cause by the wave action and the engine. Such measurements, both in the time and frequency domains, can help to identify consistency over long periods and even possibly changes in the characteristics which could possibly help to identify anomalies or damage in such a ship as well as helping ship architects and designers with future conceptions.

V. ACKNOWLEDGEMENTS

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