163 MEASUREMENT OF HELICOPTER ROTOR BLADE VIBRATION MODES USING FIBRE OPTIC SENSING TECHNIQUES

Thomas Kissinger[1], Simone Weber[2,3], Edmond Chehura[1], James Barrington[1], Stephen Staines[1], Stephen W. James[1a], Mudassir Lone[2] and Ralph Tatam[1]

[1]Engineering Photonics, Cranfield University, Cranfield, MK43 0AL, United Kingdom
[2]Centre for Aeronautics, Cranfield University, Cranfield, MK43 0AL, United Kingdom
[3] Airbus Helicopters UK, 128 Langford Lane, Kidlington, OX5 1QZ, United Kingdom
[a]s.w.james@cranfield.ac.uk

Abstract. Two fibre-optic sensing techniques were evaluated and compared in a ground vibration test on a full-scale helicopter blade, with verification by measurements made using accelerometers. The first technique used an array of fibre Bragg gratings to monitor the amplitudes of the mode frequencies at specific locations along the blade. The second approach employed a novel direct fibre optic shape sensing (DFOSS) technique to directly measure the shape of the blade and characterise its modal frequencies. It is shown that modal frequencies can be detected with both techniques. However, only the DFOSS approach can detect all modal frequencies using a single sensor array. Crucially, the DFOSS approach provides ease of installation, as no strain transfer to the structure-under-test is required and thus its use can significantly speed up ground vibration test campaigns.

Introduction

There is great interest within the aerospace community in novel methods for the ground vibration testing of aerodynamic structures, particularly when the method reduces the high costs involved with vibration testing campaigns. Here, fibre optic sensors offer particular advantages, as they allow the multiplexing of many sensing elements on a single, lightweight optical fibre, significantly reducing the complexity and weight when compared with the wiring that is required for the use of an equivalent number of electrical strain gauges. In this work, we compare two fibre optic techniques: 1) FBG-based strain sensing [1] and 2) Direct Fibre Optic Shape Sensing [2] (DFOSS). The first technique is comparable to the use of conventional electrical strain gauges, but it is possible to multiplex up to 16 fibre-optic strain gauges along a single optical fibre using a commercially available interrogator. In common with the use of electric strain gauges, strain transfer to the fibre-optic gratings has to be established through the use of adhesives, which requires extensive preparation for attachment and removal of sensors. Conversely, the DFOSS technique evaluates the shape from differential strain measurements of three optical fibres that are all contained within a single, robust plastic rod of ~3mm diameter, allowing the independent measurement of movements in both horizontal and vertical directions. In DFOSS, as the shape and movements of the plastic support structure itself are measured, there is no requirement for the existence of strain transfer from the structure to the sensing rod, the only requirement is that the sensing rod follows the movements of the structure-under- test, which can be readily achieved through the use of adhesive tape, allowing rapid installation of the sensing element.

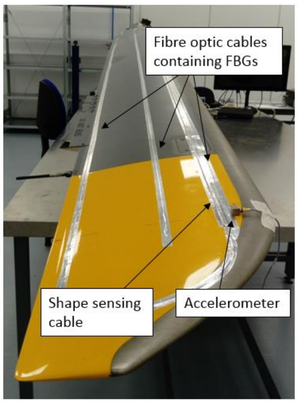

Figure 1: Blade Instrumentation

The DFOSS technique is based on our fibre-segment interferometry [3] (FSI) approach, which achieves very high-strain sensitivities, well below nanostrain·Hz$^{-0.5}$, for long-gauge length fibre-optic strain sensors that span the length of fibre separating pairs of in-fibre partial reflectors. The approach uses a novel range-resolved interferometric signal processing approach [4], which employs a robust telecoms DFB laser in a very simple optical configuration. A preliminary assessment of the performance of the two optical fibre sensing approaches has been carried out via a series of ground vibration tests (GVT) on a full scale Airbus Helicopters H135 rotorblade, shown in Figure 1. Modal spectra obtained from each set of sensors are compared against each other, highlighting the ability of fibre optic sensor systems to capture the dynamics of complex structures. The preliminarily validation of the data from both of the fibre-optic measurement approaches was achieved through the simultaneous acquisition of accelerometer data.

Experiment

The rotor blade was excited by a random-on-random (RoR) vibration signal in a frequency range of 0-100 Hz through a shaker via a stinger that was attached to the pitch control cuff. Six fibre optic cables, each containing nine wavelength-division-multiplexed FBGs, were mounted on the top and bottom surfaces of the rotor blade, located close to the leading edge at the quarter chord line, at the half chord position, and close to the trailing edge. Correct bonding is important for the FBG sensors for appropriate strain transfer from the structure to the sensor. The FBG sensors have been attached using a cyanoacrylate adhesive and in order to protect the fibre optic cables, strips of aluminium speed tape covered the length of the FBG arrays. The DOFSS sensor cable comprised three optical fibres mounted within a rectangular 3x4 mm 3D printed support structure. Each fibre contained seven sensing sections formed between eight low reflectivity broadband Bragg reflectors. The support structure was designed to hold the fibres such that changes in the shape of the structure in two dimensions perpendicular to the fibre resulted in differential strains between the fibres, from which the shape of the structure could be determined [2]. The DOFSS support structure was secured on the upper blade surface, along the quarter chord line, using aluminium speed tape. Five accelerometers were also positioned on the quarter chord line, distributed along the span.

Results & Discussion

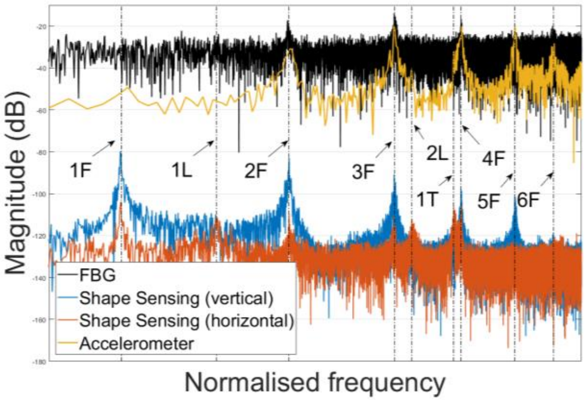

Figure 2: Spectral measurements recorded at 70% of the rotor radius comparing the sensitivity of the techniques for different modes. The modes are labelled as 1F for first flapping, 1L for first lagging, or 1T for first torsion, etc.

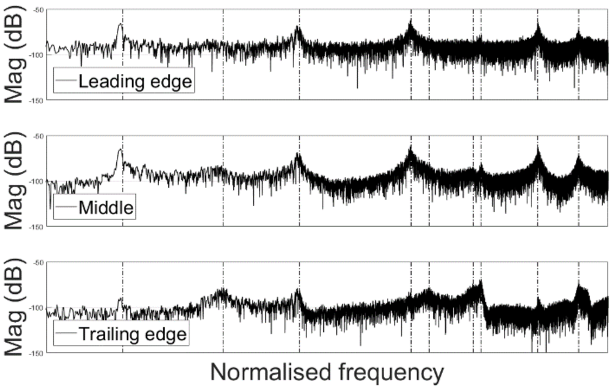

Figure 3: Frequency spectra of three FBGs on the top blade surface in the chord-wise direction at 40% of rotor radius.

Figure 2 compares the frequency spectra obtained simultaneously from all sensors that were located at the quarter chord line at 70% of the rotor radius. The shape sensing data has been separated into vertical and horizontal components, corresponding to out-of-plane and in-plane movements, respectively. To allow comparison of the sensitives of the techniques, the data has not been normalised. A total of nine resonance frequencies can be observed, where the resonance peaks of the data obtained from all of the instrumentation systems are aligned. It should be noted that, as expected, the uniaxial accelerometers could measure only the flapping modes. The DFOSS system, on the other hand, was able to detect all nine resonance frequencies, demonstrating its capability for measuring biaxial components. Comparing the vertical and horizontal components of the DOFSS data, a coupling between the structural modes is evident. However, a significant flapping/lagging coupling of the first mode was measured, which could have been induced by a component of the movement of the stinger in the in-plane direction, as the stinger was not oriented perpendicular to the blade. In the data from the FBG system, only flapping modes are observed because of its position at the quarter chord line, where the horizontal distance between neutral axis and surface is close to zero. It is clear that the DOFSS system shows a much better signal-to-noise ratio than the other techniques with a uniform distribution across the spectrum, while the accelerometer data shows an increasing sensitivity towards higher frequencies. Figure 3 compares FBG spectra from the three sensing string mounted at the top of the blade, showing that the placement of the sensors influences the modes that can be determined using this approach.

Conclusion

A number of key benefits were identified for the use of the novel DFOSS system compared to existing technologies. These range from the ease of installation to the fact that all natural mode frequencies can be extracted using a single sensor rod. Using FBGs on the other hand, an optimal distribution of the sensor elements over the surface of the rotor blade is necessary to be able to detect both lagging and torsional modes. Additionally, the data from the DFOSS system exhibited a much higher signal-to-noise ratio than that from the FBGs.

References

[1] B. Lee, "Review of the present status of optical fiber sensors," Opt. Fiber Technol. 9**,** 57–79 (2003).

[2] T. Kissinger, E. Chehura, S.E. Staines, S.W. James and R.P. Tatam, "Dynamic fiber-optic shape sensing using fiber segment interferometry", J Lightwave Tech, 36(4), pp.917-925, (2018).

[3] T. Kissinger, R. Correia, T.O.H. Charrett, S.W. James and R.P. Tatam, "Fiber segment interferometry for dynamic strain measurements", J Lightwave Tech, 34(19), pp.4620-4626, (2016).

[4] T. Kissinger, T.O.H. Charrett and R.P. Tatam, "Range-resolved interferometric signal processing using sinusoidal optical frequency modulation", Opt. Express 23(7), pp.9415-9431, (2015).