Th-D18 – High Strain FBG sensors for structural fatigue testing of military aircraft

Summary

This poster reports on a series of tests investigating the performance of Draw Tower Gratings (DTGs) combined with custom-designed broad area packaging and bonding techniques for high-strain sensing applications on Defence platforms. The sensors and packaging were subjected to a series of high-strain static and cyclic loading tests. A summary of these results is presented and compared to the performance of stripped and re-coated Fibre Bragg Gratings (FBGs)

Introduction

The structural airworthiness of the Royal Australian Air Force (RAAF) is founded on a rigorous program of full-scale fatigue testing. Test loads simulating the extreme of aircraft flight conditions are generated and applied to the aircraft using custom-designed servo-hydraulic or mechanical loading systems. In Figure 1, these full-scale ground fatigue tests require large amounts of experimental strain data from across the structure to validate the predicted strain fields. The strain sensors are required to operate under relatively high strains for a large number of cycles in order to determine the fatigue limits of the structure. These measurements are conventionally made using electrical resistance foil gauges which require three insulated leads per sensor. There is a significant weight associated with the foil gauge wiring which can affect the structural response. The foil gauges can also be less durable than the structure under test which requires replacement of the sensors midway through the testing cycle.

Although FBGs potentially offer many advantages over conventional foil gauges, there is limited conclusive information regarding these sensor’s reliability and durability.

Sensor Fabrication

There are typically four main steps involved in fabrication of a fibre Bragg grating: 1. Removal of the fibre coating. 2. Photosensitization of the fibre. 3. Exposure of the grating to UV laser light. 4. Annealing and Re-coating/packaging.

Each of these steps in the process has the potential to introduce structural flaws to the glass surface which weakens its ultimate strength and long-term reliability. Nearly all of the commercially-supplied gratings are fabricated in a unidirectional orientation \([(+45,-45)3\text{s}]\) with dimensions of 200 mm x 25 mm manufactured to American Society for Testing and Materials (ASTM) standards. Aluminum grip tabs were bonded to each coupon to protect the coupon from the load-cell grips during tensile loading in a mechanical test machine as shown in Figure 6. The uni-directional test coupon had a predicted strain-to-failure of 40,000 µ in with a linear stress-strain response curve to the yield strain at approximately 18,000 µ. The cross-ply coupons had a much higher strain-to-failure (9%), with a non-linear response beyond the yield point of the material at approximately 1,000 µ.

Sensor Packaging Techniques

For broad-area structural assessment and health monitoring of large Defence platforms, a robust and viable technique is required for surface-mounting a network of sensors onto a large structure, as shown schematically in Figure 1. DSTO have developed two different packaging techniques considering pre-packaging, transportation, alignment, packaging, mounting and protection. The first technique is a Vacuum Assisted Resin Transfer Moulding (VARTM) as shown in Figure 4.

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This poster studies the performance of FBGs inscribed during the fibre fabrication process known as DTGs. The performance of these DTGs under static and fatigue loading conditions on a series of fibre glass test coupons using different surface-mount adhesive techniques is presented and compared to the performance of stripped and re-coated FBGs.

Results

Optical fibres are typically coated to provide a hermetic seal which provides environmental and mechanical protection. The fibre interrogation process requires the removal of this coating which has been reported to reduce the mechanical strength of the optical fibre [4]. The most common coating removal methods were investigated in previous work [2] which showed that CO2 Laser ablated fibres endured the highest strain to failure tests of stripped and re-coated FBGs.

Figure 8 shows the average strain-to-failure levels for both the CO2 stripped FBGs and the DTGs using both the VARTM and Redux packaging. The results indicate that both packaging techniques, the strain-to-failure for the DTGs is approaching the expected level for that of the pristine optical fibre (approximately 1% or 10,000 µ). The strain-to-failure levels for the CO2 stripped FBGs are significantly lower than for the DTGs.

Figure 8: Comparison of Average Strain to failure for DTGs and CO2 laser stripped FBGs in Redux and VARTM packaging.

Figure 5 shows the number of cycles at 10,000 µ before fibre failure for the DTGs only. The results indicate that the Redux packaging performed slightly better than the VARTM packaging under fatigue loading conditions. As the fatigue loading progressed there was also evidence of strain gradients along the length of the grating as indicated in Figure 7 spectra particularly for the VARTM packaging. This may be occurring due to micro-cracking which was observed in the resin matrix.

Figure 9: Comparison of number of cycles for DTGs in Redux and VARTM packing.

Conclusions

The results of the investigation into the effect of the manufacturing process on the reliability and durability of Fibre Bragg Gratings (FBGs) clearly show that Draw Tower Gratings (DTGs) demonstrate significantly better performance than FBGs which have been written into stripped and re-coated fibres. The associated packaging has also performed well under these extreme loading conditions. With recent enhancements in DTG fabrication technology, the reflectivity of these gratings should be suitable for use with many commercially available FIB integrators. For these reasons, the use of DTGS show promise for structural health monitoring applications where long term use in harsh and high strain environments is required.

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