Aerospace qualification of SmartScan Aero-mini Interrogator

Hasula Dias[(a)*], Kevin Jones[(a)], Emily Stainthorpe[(a)], Jerome Grelin[(a)], Crispin Doyle[(a)], Chris Staveley[(a)]

[a]*Smart Fibres LTD, Brants Bridge, Bracknell, Berkshire RG12 9BG, United Kingdom*

Abstract *This paper presents the qualification testing and evaluation of the SmartScan Aero mini interrogator. The high speed aerospace interrogator enables high resolution strain measurements at multi-kHz frequencies, and is qualified to military standard (MIL-STD) 810G. We present the proof of performance in environments of vibration, shock, and a range of temperatures from -40 ^{0}C to +60 ^{0}C. We also present initial performance results with exposure to Co-60 Gamma radiation.*

Keywords: Optoelectronic reliability, Optoelectronic interrogator, Health and usage monitoring, aerospace

I. INTRODUCTION

Health and Usage Monitoring Systems (HUMS) are highly desirable for predictive aerospace maintenance as they allow scheduling maintenance to prevent critical failures and their consequences. Over the past two decades, optical fibre Bragg grating (FBG) structural health monitoring systems have become well-known, as a repeatable and non-destructive evaluation (NDE) technology where optoelectronic interrogators play a vital role **[1]**. Previous generations of Smart Fibres interrogators, SmartScan Aero and Wx, underwent numerous flightworthiness trials on a project known as Active Health Monitoring System (AHMOS), a BAE systems Hawk aircraft during AHMOS2 **[2]**, and also on unmanned aerial vehicles (UAVs), logging more than 1000 flight hours **[3]**.

The SmartScan Aero mini is a robust and small form factor FBG interrogator for dynamic strain measurements at multi-kHz frequencies. It possesses improved features compared to its predecessors (SmartScan Aero and Wx), such as on-board data logging, and is optimised for avionic installation in military, civil or unmanned aircrafts.

In this paper, we present the qualification testing and evaluation of the SmartScan Aero mini interrogator. Section II describes the environmental testing of the interrogator, which includes vibration and shock testing with respect to military standard (MIL-STD) 810G **[4]**, and thermal cycling in the range of -40 ^{0}C to +60 ^{0}C. This is followed by section III, which describes radiation testing of the interrogator hardware.

II. ENVIRONMENTAL TESTING

The purpose of the environmental tests was to determine the ability of the SmartScan Aero mini to withstand the environmental conditions without any failure, malfunction, or out of tolerance issues. In order to achieve this, the unit under test (UUT) was subject to random vibration and shock testing as well as thermal cycling in a climatic chamber.

The vibration testing was conducted in accordance with MIL-STD 810G, Method 514.6, Annex D, Category 12, over the frequency range of 1.5-2 kHz for a period of 30 minutes. The test setup consisted of a personal computer (PC), connected to the UUT via an Ethernet cable, and three athermal FBG test articles (1534.810 nm, 1549.689 nm and 1564.913 nm), which were connected *via* the fibre optic cable. The UUT, shown in Fig. 1, was mounted on a vibration/shock platform and the athermal FBGs were mounted such that they have nearly no response to temperature and are isolated from strain. This ensures changes in their reflected wavelength would indicate that the UUT is being affected by vibration.

Fig. 1: SmartScan Aero mini interrogator

*Corresponding author. e-mail: hasula.dias@smartfibres.com

Additionally, before the vibration test was applied, the interrogator was allowed sufficient time to stabilise in the vibration testing setup to minimise the sensitivity of wavelength change due to instrument temperature changes. Thereafter, during the testing, the athermal FBGs centre wavelengths were logged using interface software of the unit. The results obtained from the vibration testing are shown in Fig. 2, and they show the wavelength stability of the Smart Scan Aero-mini under vibration is well within the specification of ± 5pm **[5]**.

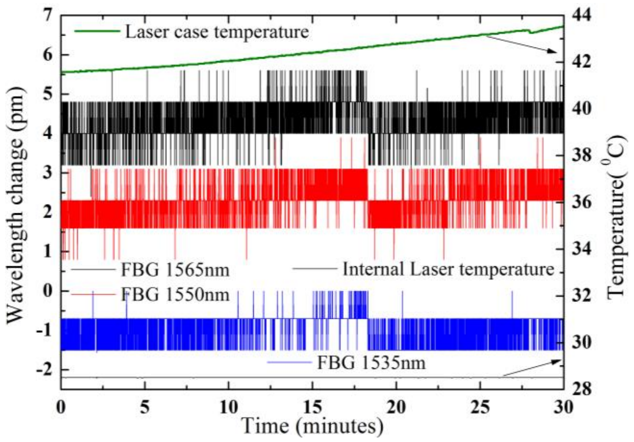

Fig. 2: Vibration testing results of the SmartScan Aero mini interrogator

The shock testing was conducted in accordance with MIL-STD 810G Method 516.6, Procedure I. The shock testing setup was similar to the vibration test setup. The results obtained from the shock testing are shown in Fig .3. The results show the change in FBG reflection wavelengths and prove the SmartScan Aero-mini wavelength stability under shock testing is well within the specifications of ± 5pm **[5]**.

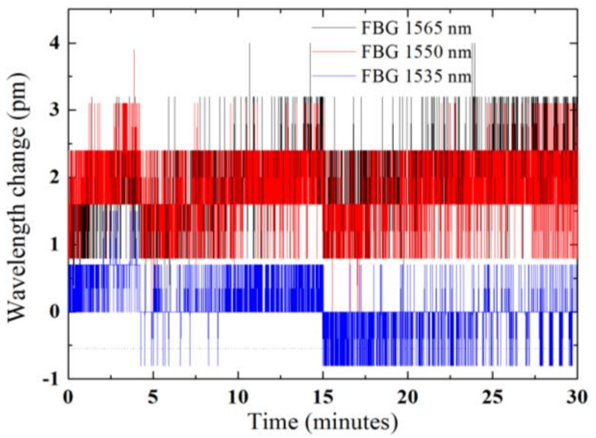

Fig. 3: Shock testing results of the SmartScan Aero mini interrogator

For the thermal cycling phase, the UUT was placed in a climatic chamber and athermal FBGs were placed in a temperature controlled dry well. This ensured that any changes in their reflected wavelength would indicate that the UUT is being affected by the ambient temperature of the climatic chamber. The chamber was programmed to cycle between a minimum of -40 ^{0}C to maximum of 60 ^{0}C, and the UUT was allowed to stabilize at each new temperature point. The results of the thermal cycling test are shown below in Fig. 4.

The change in wavelength over the duration of the test at each temperature is due to the change in the interrogator temperature. Fig. 4 also shows an increase in the FBG reflection wavelengths when the UUT is subjected to temperatures below 0 ^{0}C. This is due to the internal heater which prevents catastrophic failure at low temperatures.

Fig. 4 shows the SmartScan aero mini wavelength stability is well within the specifications of ± 5pm, over wide temperature range. The lowest limit was set due to climatic chamber limitations and some sub-component ratings of -40 ^{0}C. The highest sub-component ratings were +85 ^{0}C. Given the instrument circuitry includes safety features to avoid catastrophic failure and wavelength stability over an operating temperature range is optimised using an algorithm, it can be surmised that performance could be maintained to greater temperature limits.

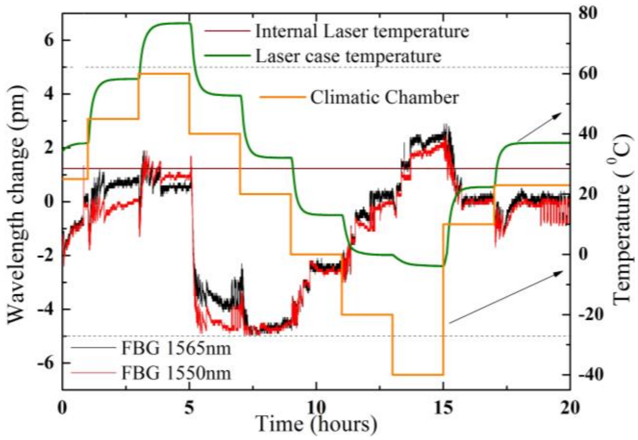

Fig. 4 Temperature cycling test results of the SmartScan Aero-mini interrogator

III. RADIATION TESTING

Radiation testing of SmartScan Aero mini hardware was performed at Fraunhofer INT's (*Institut für Naturwissenschaftlich-Technische Trendanalysen*) TK 1000B gamma facility in *Euskirchen*, as part of the design requirements for the European Institute of Innovation & Technology (EIT) Knowledge and Innovation Community (KIC) InnoEnergy project on Development of Hard Optical Fibre Bragg Gratings (HOBAN).

Prior to testing, the dimensional volume of the instrument was used to calculate the distance between the UUT and the gamma radiation source, and to ensure the correct dose was applied to the UUT. A dose rate of 16.8 Gy(SiO_2)/h was used to target total integrated dose (TID) of pre-specified amount. The UUT was placed on a vertical translation stage with its core components centred directly below the tip where the radiation source is located. The height and the lateral position ensured the UUT was exposed to the correct dose. A schematic of the test setup is shown in Fig. 5. Two athermal FBGs (1535 nm and 1565 nm) were mechanically mounted such that their reflected wavelength would indicate the UUT is being affected by radiation.

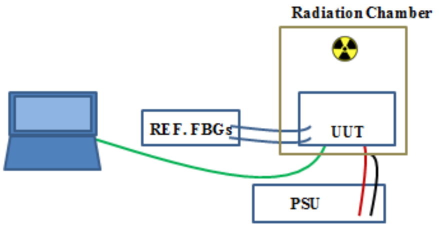

Fig. 5 Radiation testing setup of the SmartScan Aero mini interrogator

Over the duration of the radiation testing scheme, a TID of 60 Gy(SiO_2) caused a change in performance of the UUT, where the accuracy of the output wavelength experienced a step change which was not consistent across the emission spectrum of the laser. A TID of 80 Gy(SiO_2) caused a shift of -40 pm at 1535 nm and -22 pm at 1565 nm. Furthermore, the current drawn by the instrument also increased for higher doses of radiation. The increase in the current drawn by the UUT may have been due to ionizing radiation which leads to a decrease in the quantum efficiency of the laser. Similarly, the change in emission spectrum could be a result of an increase in non-radiative recombination centres of the laser **[6]**.

IV. CONCLUSION

The SmartScan Aero-mini is a compact and robust aerospace interrogator for dynamic measurement of FBG sensors. The aerospace interrogator is optimised for avionic installation in military, civil, or unmanned aircrafts by qualification to MIL-STD 810G standard. The results presented in section II is proof of performance in environments of vibration (with respect to MIL-STD 810G, Method 514.6, Annex D), shock (with respect to MIL-STD 810G Method 516.6), and temperatures in the range of -40 ^{0}C to +60 ^{0}C. In addition to these standards, the SmartScan aero mini is also ATEX compliant for zones 0, 1, or 2, with gas groups IIA, IIB or IIC, and electro-magnetic compatibility (EMC) compliant against EN 61326. Future work will ensure the SmartScan Aero-mini maintain stable operation at temperatures of -55 ^{0}C to +75 ^{0}C.

The results presented in section III are some of the first tests of SmartScan Aero mini hardware operation with exposure to gamma radiation. It is expected further testing and design will help drive the performance of next generation of SmartScan interrogators to be operable in harsher environments.

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