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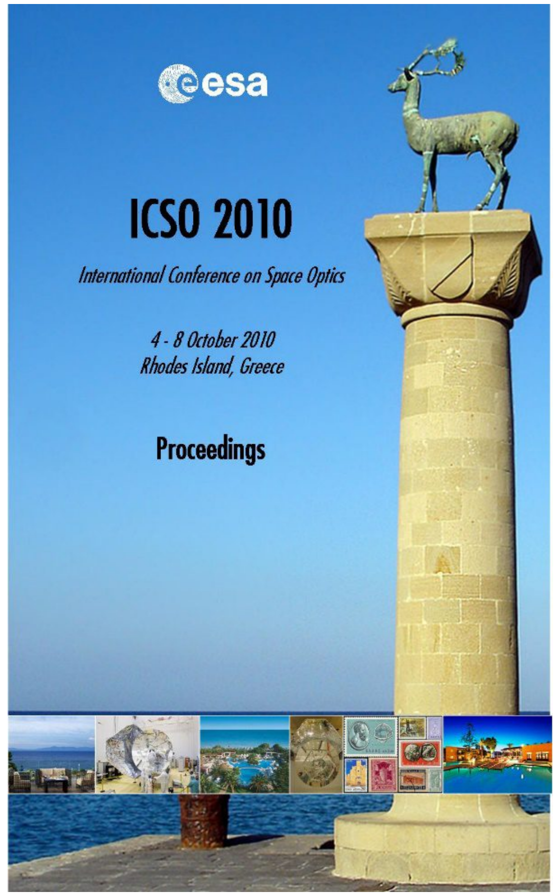

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DEVELOPMENT OF FIBER OPTIC SENSING INTERROGATORS FOR LAUNCHERS

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INTRODUCTION

We present our work about the development of two complementary interrogation schemes based on fiber optic sensing for the use of structural and thermal monitoring of Ariane launchers. The advantages of fiber optic sensing in particular light-weight, immunity to electromagnetic interferences and the possibility of sensor distribution along optical fibers are driving factors for utilization of this technology in space crafts [1]. The edge-filter (EF) and scanning-laser (SL) interrogators for determination of the mean wavelength of fiber Bragg grating (FBG) sensors have been implemented as two separate demonstrators. Within this paper we describe the functional principles of both interrogators. Furthermore we present test results where the developed systems have been used for readout of FBG sensors which are implemented in an Ariane structural demonstrator during thermal, thermal-vacuum and vibration tests. Functionality of both systems is demonstrated and their potential for further development towards space qualified systems is shown.

Since the performance characteristics of the two systems are different from each other, they are dedicated for different sensing applications on a launcher. The EF sensor interrogator provides a sample rate of 20 kHz at a number of 4 connected sensors and supports parallel readout and aliasing free operation. Therefore it is best suited for high priority measurement. Structural monitoring which requires the acquisition of real time sensor information in order to support control of the launcher is one operation area for a future EF system. The SL interrogator provides an overall measurement rate of 1 kHz at a number of 24 connected sensors distributed on three sensor channels. It can be adapted to any sensors that have design wavelengths lying within the output spectrum of the laser diode. Furthermore the number of overall sensors to be read out with this system can be adapted easily. Thermal mapping of satellite panels is one possible future application for the SL interrogator.

MEASUREMENT SETUP

The first interrogator is based on an edge-filter (EF) design, where a broadband light source is used to illuminate the sensor fiber (see Fig. 1). Light that is reflected by a FBG sensor enters an arrayed waveguide grating (AWG) located inside the interrogator. The AWG is designed in a way that a set of two adjacent channels act like two band pass filters that overlap spectrally. The reflected light of the sensor passes both channels; the intensities that are measured with photo detectors at the AWG outputs are dependent on the spectral position of the sensor peak. Determining the intensity ratio of the two photo currents therefore yields the spectral response of the FBG sensor [2].

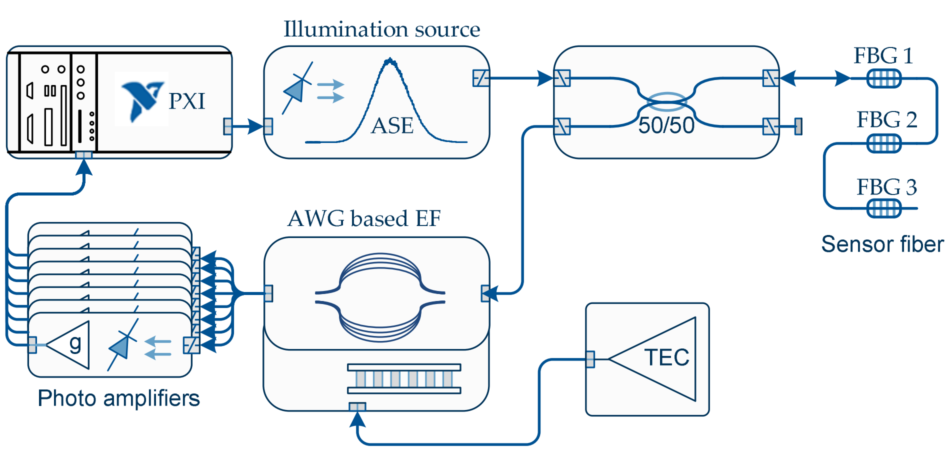

Fig. 1. EF interrogator. An autonomous spontaneous emission (ASE) light source illuminates the FBG sensors. Light that is reflected by the sensors is guided to an AWG configured as EF.

Resulting photo currents are converted by photo amplifiers and evaluated by a computer system.

The second interrogation scheme is based on a scanning-laser (SL) design using a monolithic tuneable laser diode to spectrally sample the FBG sensor (see Fig. 2). The reflected intensities are measured using a photo detector. The mean wavelength of the sensor peak is calculated with a specially developed centroid algorithm. A set of three input currents to the laser diode determines the output wavelength. Therefore, it is possible to switch to every wavelength within the output spectrum of the laser within less than a microsecond. Spectral gaps between two consecutive sensors can be skipped and overall sensor measurement rate is optimized [3],[4].

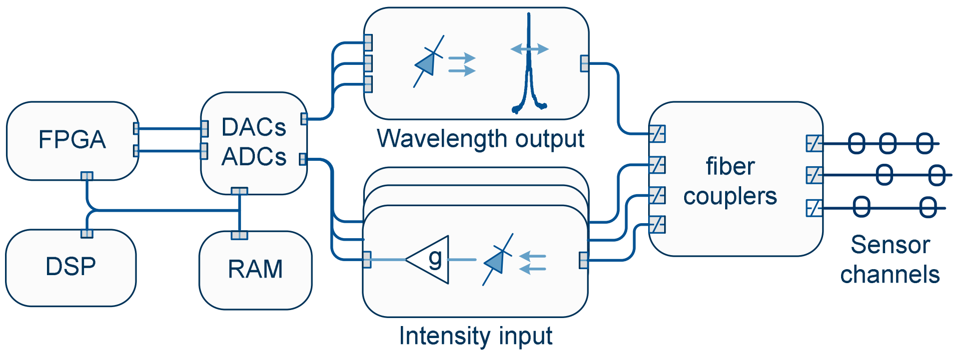

Fig. 2. SL interrogator. The output wavelength of the laser diode is controlled by three input currents generated by digital to analog converters (DAC). Intensities of light pulses that are reflected by a FBG sensor are measured and digitized. A centroid algorithm implemented in a digital signal processer (DSP) calculates the mean wavelength of the sensor.

THERMAL AND THERMAL-VACUUM TESTS

The structural demonstrator with implemented FBG sensors was installed in thermal and thermal-vacuum chambers in order to carry out the environmental tests. Thermal cycling with identical temperature plateaus was performed during both test sequences. Electrical sensors were mounted next to the FGB sensors which allowed a calibrated temperature reference measurement. No differences in the measurement of wavelengths have been observed when both test results were compared after the tests. Thereby the expected independency of FBG sensor measurement from vacuum environment was demonstrated.

Fig. 3 shows one measurement cycle of a thermal test with temperature plateaus at 30, 40, 50 and 60°C measured with the SL interrogator. Deviations of the FBG temperature from the electrical reference measurements are due to inaccuracies of the laser characterization [3], which will be eliminated in future by improved sensor calibration. Linear approximation of the ratio of measured wavelength response of the FBG sensor and reference temperature of the electrical sensor resulted in a sensitivity of the FBG sensor of

$$\frac{\Delta\lambda_{FBG}}{\Delta T} = 12.6\,\frac{pm}{K}\,. \qquad (1)$$

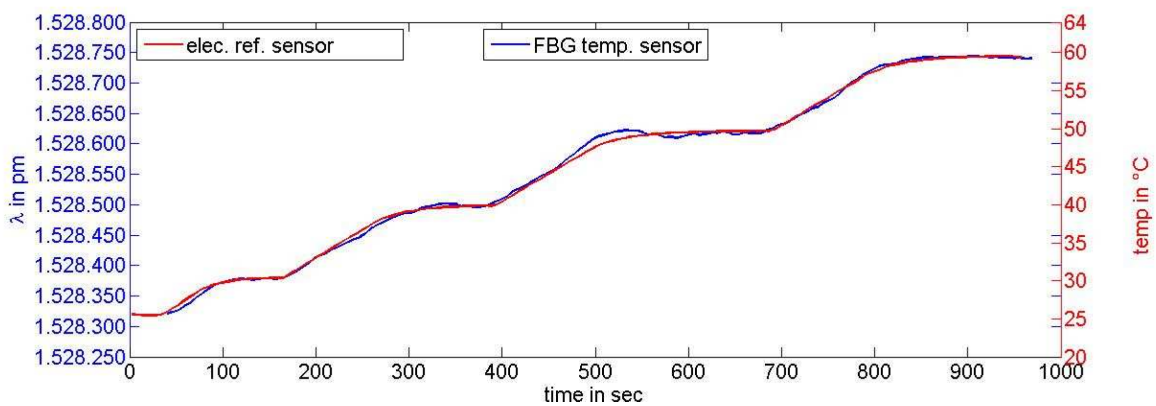

Fig. 3. An FBG configured as temperature sensor was read out with the SL interrogator. An electrical reference sensor confirms the measurement results.

VIBRATION TESTS

Vibration tests of the structural demonstrator have been performed and both, the SL and EF interrogator have been used for wavelength measurement of the mounted FBG sensors. Since the SL interrogator is still under development, the overall sampling frequency only reaches a value of 128 Hz. Therefore structural vibrations at frequencies up to 65 Hz can be measured. The upper part of Fig. 4 shows a measurement, where the structure was sinusoidal excited with a frequency of approximately 30 Hz. At the lower part of Fig. 4, the vibration frequency was too high and beat nodes occur due to under-sampling.

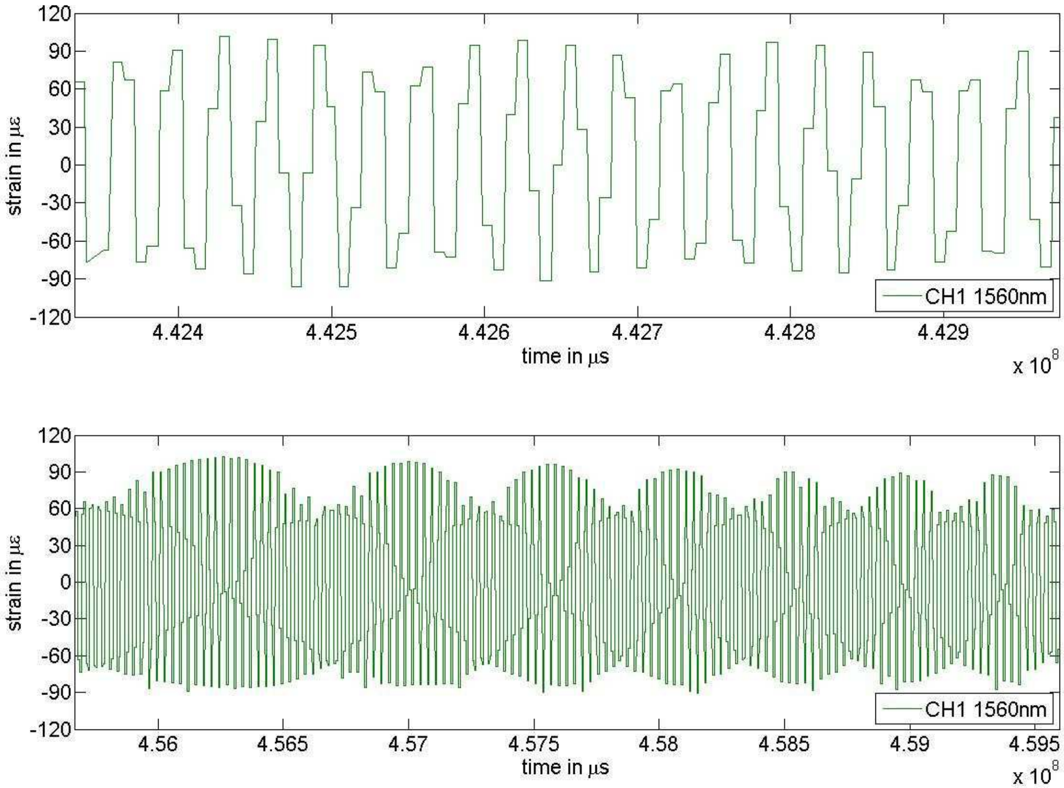

Fig. 4. One FBG sensor with a design wavelength of 1560 nm measured with the SL interrogator during frequency sweep of the structural demonstrator (top: 31 Hz excitation frequency). Vibration measurement shows beat frequencies due to under-sampling when the structure is excited with frequencies higher than 65 Hz (bottom).

The EF interrogator was calibrated for vibration sensing using a setup shown at the left hand side of Fig. 5. A piezo stack was used to apply a sinusoidal strain to a FBG sensor under test. The right hand side of Fig. 5 shows the result of the EF measurement. Additionally a second FBG sensor connected to the EF system was evaluated in order to ensure the absence of crosstalk between sensors connected to the EF interrogator.

The measurement results obtained with the EF interrogator during vibration test of the structural demonstrator are shown in Fig. 6. The demonstrator was excited with a frequency sweep from 10 Hz to 2 kHz. Simultaneously an electrical reference sensor was measured for comparison of measurement results.

CONCLUSION

Thermal, thermal-vacuum and vibration tests on a structural demonstrator have been performed and fiber optic FBG sensors implemented in the demonstrator have been measured online. The test results clearly demonstrate the functionality of the developed edge-filter and scanning-laser interrogators. Further developments of the interrogators include the enhancement of overall measurement rate of the SL system towards kilo-Hertz region and adjustment of the hardware of both interrogators in order to support space qualification of the measurement systems.

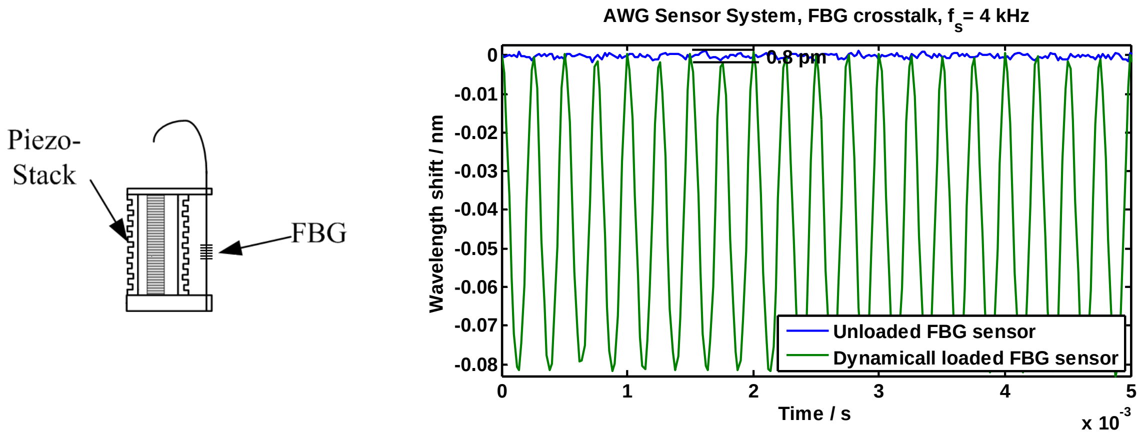

Fig. 5. Left: A vibration test stand was developed prior to the test in order to apply a dedicated frequency to a FBG sensor. Right: Measurement of a 4 kHz vibration using the EF interrogator.

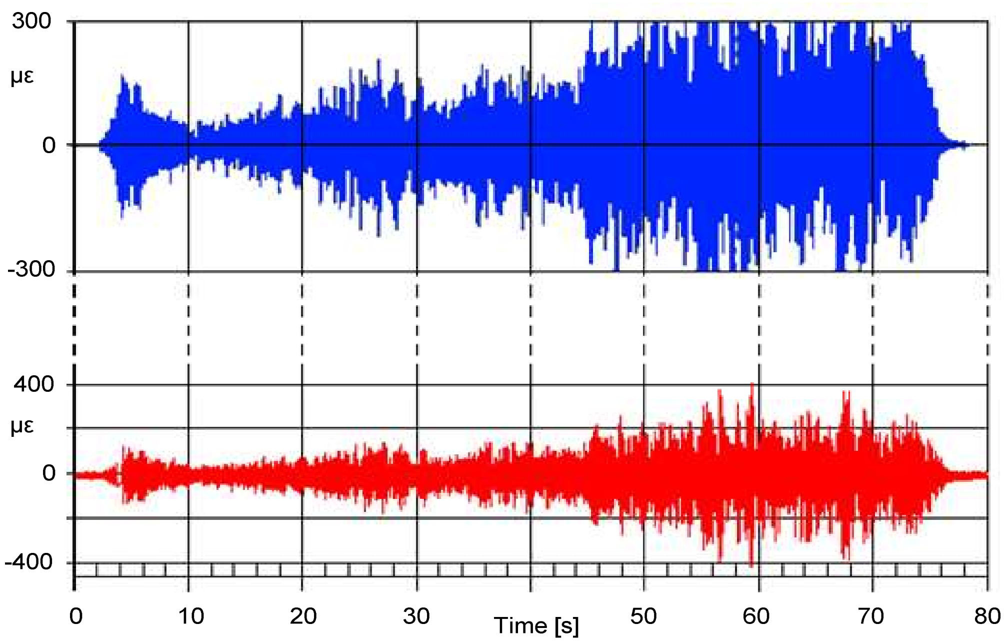

Fig. 6. Comparison of strain measured by EF (top) and electrical reference sensor (bottom).

ACKNOWLEDGEMENT

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